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11

る。したがって、電子線の観察範囲 $\theta$ と異なる範囲 $\alpha$ で外界を観察可能となる。このように、観察者が外界像と電子線を部分領域別に観察することは、例えば、観察者が観察者視野の中で、上側領域で外界を観察し、下側領域で電子線を同時に観察することができることである。ただし、この部分領域別とは、上下、左右等、観察者が部分的にそれぞれを観察できればどのような方向、領域に分かれていても構わない。このような機能を得ることで、観察者が画像表示装置を装置したまま外界を認識できるため、危険防止と緊急時に対応できる安全な画像表示装置を提供することができる。そのため、画像表示装置としてのグラフィックジョンの幅が広がることとなる。

【0042】この像形成装置において、像形成手段としては、第4面に像形成面を対向配置させたLCD、CRT等の画像表示素子（リレー光学系によってリレーされるものは予定していない。）であり、第2面は曲面にて形成されていることが望ましい。

【0043】また、このような像形成装置において、画像表示素子と接視光学系を観察者眼球前方に保持する作用を持った保持部材を設け、プリズム部材、画像表示素子が第3面から射出した光束が、第4面から入射し、その入射光束が第3面で反射され、その反射光束が第1面で反射され、その反射光束が第2面へ反射され、その反射光束が第1面から射出されるように構成することにより視野狭窄型画像表示装置として構成することができる。

【0044】また、以上の像形成装置において、プリズム部材が、像形成手段によって形成された像の観察時及び外界像の観察時の何れの観察においても、同じ位置に固定したものとすることができ、その場合、下記の図7を用いて説明するように、第1面と前記第3面を通して、部分領域別に像形成手段からの像と外界像を観察可能であることが望ましい。

【0045】また、プリズム部材に、像形成手段によって形成された像の観察と外界像の観察とを切り替える切替手段を設け、その切替手段によりプリズム部材を移動させるようにしてもよい。

【0046】すなわち、接視光学系の観察者眼球直前に配置してある第1面と、外界側に配置し主光線の一部が全反射している第3面が観察者視線付近になるように移動することによって、観察者はまっすぐ正面を向いた場合の視線の周辺、つまり、視野の中心付近において外界像を観察できるため、画像表示装置を装置したまま観察者の目の前の外界を確認することができ、安全性を確保した画像表示装置を実現できる。

【0047】また、電子線を表示したままであれば、接視光学系を移動したり戻したりすることによって、外界像と電子線を切り替えることができる。したがって、グラフィックジョンの幅が広がることとなる。

【0048】この場合、切替手段は、前記像形成手段に

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よって形成された像を観察する際、プリズム部材から観察者視野に到る光路が、外界像を観察する際、プリズム部材から観察者視野に到る光路と略一致するようにプリズム部材を移動させることが望ましい。

【0049】また、プリズム部材の移動が軸上主光線の光路を含む面に沿った方向に移動するように、移動の自由度が高くなるため、移動機構、装置全体のレイアウトが容易となり、安価な画像表示装置を実現できる。

【0050】また、プリズム部材の移動が視線に垂直方向への移動可能であるため、装置全体のレイアウトや移動機構が容易であるとは言ってもなく、接視光学系の移動後も観察者前面向きの突出量は変わらないので、小型でコンパクトな画像表示装置を提供できる。

【0051】また、プリズム部材が回転可能であると、プリズム部材が容易な回転機構によってプリズム部材を移動することで外界を観察することが可能であるため、機構自体は安価になり、さらに、左右同時に回転するようにすることで、同様に外界を確認可能のため、安全性も高まり、装置のレイアウトも簡単な構成で実現できる。

【0052】また、本発明のうち1つの像観察装置は、像形成手段、前記像形成手段によって形成された像を観察領域に導く作用を持った接視光学系とを有する像観察装置において、前記接視光学系が少なくともプリズム部材を含み、前記プリズム部材は、その面領域の中、透過又は反射の光学作用を持った光学作用面が少なくとも4つ設けられ、かつ、その4つの光学作用面とそれ以外の面で囲まれた面（面積比率（ $\eta$ ）が1よりも大きい（ $\eta > 1$ ））単体構造で設けて構成され、前記4つの光学作用面は、透過作用と反射作用とを有し観察者視野側に配置された第1面と、前記第1面に対して前記透過作用を有する第2面と、前記第2面に対して前記透過作用を有する第3面と、一方の端部を前記第1面に傾斜させた他方の端部を前記第3面に接近させるように配置した第4面とからなり、少なくとも前記第3面は全反射作用を有するように前記プリズム部材が構成されていると共に、前記第1面と前記単体構造と前記第3面を通して外界を観察することが可能な外界観察作用を有するように前記第1面と前記単体構造と前記第3面とが構成されていることを特徴とするものである。なお、上記において、4つの光学作用面以外の面とは、光学作用のないプリズム側面やカット面を意味する。

【0053】これらの像観察装置においては、観察者眼球直前に配置してある面と前記接視光学系の外界側に配置してある面を通して外界を観察可能のように構成されている。図7を用いてこの作用効果について説明する。

図7は光軸に対して傾いた4つの面3、4、5、6に

13

よって形成された空間を断面率が1より大きい媒質によって満たされた偏心プリズム12の断面図であり、図中、1は観察者の眼、2は観察者視線、3は接視光学系12の第1面、4は第2面、5は第3面、6は第4面、7は画像表示素子、12は接視光学系、15は観察者眼球、16は光学ファインダーであり、実際の画像表示素子7からの光線経路は、画像表示素子7を有した光路が、接視光学系12の第4面6に入射し、第3面5で全反射し、第1面3で全反射し、第2面4で反射され、再び第1面を通過して観察者の眼1を射出像として観察者眼球15に画像を投影している。

【0054】本発明の像観察装置は、第3面5は全反射面であり反射コーティングをしていないため、第3面5と第1面3を透過する外界光は観察者眼球15に到達する。したがって、電子線の観察範囲 $\theta$ と異なる範囲 $\alpha$ で外界を観察可能となる。このように、観察者が外界像と電子線を部分領域別に観察できることは、例えば、観察者が観察者視野の中で、上側領域で外界を観察し、下側領域で電子線を同時に観察することができることである。ただし、この部分領域別とは、上下、左右等、観察者が部分的にそれぞれを観察できればどのような方向、領域に分かれていても構わない。このような機能を得ることで、観察者が画像表示装置を装置したまま外界を認識できるため、危険防止と緊急時に対応できる安全な画像表示装置を提供することができる。そのため、画像表示装置としてのグラフィックジョンの幅が広がることとなる。

【0055】この像形成装置において、像形成手段としては、第4面に像形成面を対向配置させたLCD、CRT等の画像表示素子（リレー光学系によってリレーされるものは予定していない。）であり、第2面は曲面にて形成されていることが望ましい。

【0056】また、このような像形成装置において、画像表示素子と接視光学系を観察者眼球前方に保持する作用を持った保持部材を設け、プリズム部材が、画像表示

$$-0.5 \leq \phi_{11} \leq 0.5 \quad (1/\text{mm})$$

を減らすことが望ましい。ただし、 $\phi_{11}$ は軸上主光線を含む面内の $\phi_{11}$ （ $y_2$ ）とその面に垂直な面内の $\phi_{11}$ （ $x_2$ ）それぞれに対向する。（3）式の条件を満たすことによって、外界光が偏心プリズムを透過する場合の光束が1近傍に設定することができるため、より自然な外界を観察できる。

【0060】また、以上の像観察装置において、プリズム部材が、像形成手段によって形成された像の観察時及び外界像の観察時の何れの観察においても、同じ位置に固定したものとすることができ、その場合、上記図7を用いて説明するように、第1面と前記第3面を通して、部分領域別に像形成手段からの像と外界像を観察可能であることが望ましい。

【0061】また、プリズム部材に、像形成手段によっ

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\*素子から射出した光束が、第4面から入射し、その入射光束が第3面で反射され、その反射光束が第1面で反射され、その反射光束が第1面から射出されるように構成することにより視野狭窄型画像表示装置として構成することができる。

【0057】また、上記の像形成装置において、観察者眼球直前に配置してある面と接視光学系の外界側に配置してある面、外界光に対して前記2つの面の任意の場所における合成ビーグがゼロであるようにすることが望ましい。外界光に対する2つの面の合成ビーグがゼロであるとき、外界像の観察する姿勢が視野で観察するときと同等となり、より自然な外界を観察することができる。したがって、危険防止と緊急時には外界を的確に認識することができるため、非常に安全な画像表示装置を提供することができる。

【0058】この場合、第1面と第3面とが曲面、球面、あるいは平面にて形成することができる。観察者が外界を観察するとき、外界からの光線は外界側に配置された内部反射面の中、全反射している領域と、観察者眼球直前に配置してある屈折面を透過しては曲面に投影される。このとき、この2つの面の曲率面では曲面とすると、各面の曲率の変化がないため、斜めにおいてより自然な外界像を観察することが容易になる。また、観察者眼球直前に配置してある第1面と接視光学系の外界側に配置してある第3面が平面であるとき、各面に、その2つの面が観察者視線に対して垂直であり、さらに、その2つの面に配置されている場合には、単に透明板を通して外界を観察することになるため、非常に自然な外界像を観察することができる。

【0059】これらにおいて、外界光に対する観察者眼球直前に配置してある面と接視光学系の外界側に配置してある面との任意の場所における合成ビーグを $\phi_{11}$ とすると、

$$\dots (3)$$

て形成された像の観察と外界像の観察とを切り替える切替手段を設け、その切替手段によりプリズム部材を移動させるようにしてもよい。

【0062】すなわち、接視光学系の観察者眼球直前に配置してある第1面と、外界側に配置し主光線の一部が全反射している第3面が観察者視線付近になるように移動することによって、観察者はまっすぐ正面を向いた場合の視線の周辺、つまり、視野の中心付近において外界像を観察できるため、画像表示装置を装置したまま観察者の目の前の外界を確認することができ、安全性を確保した画像表示装置を実現できる。

【0063】また、電子線を表示したままであれば、接視光学系を移動したり戻したりすることによって、外界像と電子線を切り替えることができる。

図7は光軸に対して傾いた4つの面3、4、5、6に

て、フリテンジョンの幅が広がることとなる。

【0064】この場合、観察者領域直前に配置してある面と接眼光学系の外側に配置してある面は、外界光に対して2つの面の合成パワ－が略ゼロであるようにすることが望ましい。観察者は、外界光に対するその2つの面の合成パワ－が略ゼロであると、より自然な外界を観

$$-0.5 \leq \phi_1 \leq 0.5 \quad (1/\text{mm})$$

を減らすことが望ましい。ただし、 $\phi_1$ は軸上主光線を含む面内のフワ－ $\phi_1$  ( $y/z$ ) とその面に垂直な面内のフワ－ $\phi_2$  ( $x/z$ ) それぞれに対する。(4) 式の条件を満たすことにより、外界光が偏心フリスムを透過する場合の歪事を1近傍に設定することができる。より自然な外界を観察できる。

【0066】この場合、切替手段は、前記像形成手段によって形成された像を観察する際の前記フリスム部材から観察者眼球に到る光路が、外界像を観察観察する際の前記フリスム部材から観察者眼球に到る光路と略一致するようにフリスム部材を移動させることが望ましい。

【0067】また、フリスム部材の移動が軸上主光線の光路を含む面内かつ方向に移動するように、移動が直線的になるため、移動機構、装置全体のレイアウトが容易となり、安価な画像表示装置を実現できる。

【0068】また、フリスム部材の移動が視線に垂直方向への移動可能であること、装置全体のレイアウトや移動機構が容易であるのは言うまでもなく、接眼光学系の移動後も観察者側面の突出部は変わらないので、小型でコンパクトな画像表示装置を提供できる。

【0069】また、フリスム部材が回転可能であること、フリスム部材が容易な回転機構によってフリスム部材を移動することによって外界を観察することが可能であるため、機構自体は安価になり、さらに、左右同時に回転するようにすることで、両眼で外界を観察可能であるため、安全性も高まり、装置のレイアウトも簡単な構成で実現できる。

【0070】本発明のさらにもう1つの像観察装置は、像形成手段と、前記像形成手段によって形成された像を観察する際に、前記接眼光学系とを有する像観察装置において、前記接眼光学系が少なくともフリスム部材を含み、前記フリスム部材は、その面構成の中、透過又は反射の光学作用を持った光学作用面が少なくとも4つ設けられ、かつ、その4つの光学作用面とそれ以外の面とで囲まれた面を屈折率 ( $n$ ) が1より大きい ( $n > 1$ ) 単体媒質で埋めて形成され、前記4つの光学作用面は、透射作用と反射作用とを有し観察者領域側に配置された第1面と、前記第1面に対して前記配置された面と対向配置されかつ観察者視線に対して少なくとも偏心であるいは傾いて配置された反射作用を有する第2面と、前記第1面に対して前記配置された面と対向配置されかつ前記第2面に略略略略略略された反射作用を有する第3面と、一方の端部を前記第1面に略略略略略略他方の端部を

\*露で、危険防止や緊急時に適切に対応でき、非常に安全な画像表示装置を提供することができる。

【0065】そして、外界光に対する観察者領域直前に配置してある面と接眼光学系の外側に配置してある面との圧縮の場所における合成パワ－を $\phi_1$ とする場合、

$$\dots (4)$$

前記第3面に略略略略略略ように配置した第4面とからなり、少なくとも前記第2面又は前記第3面が全反射作用を有するように前記フリスム部材が構成されていると共に、前記全反射作用を有する前記第2面又は前記第3面の全反射作用を生じる領域近傍に観察者の視線を射出する作用を持った視線射出手段を配置したことを特徴とするものである。この場合も、4つの光学作用面以外の面とは、光学作用のないフリスム側面やカット面を意味する。

【0071】以下に、この像観察装置を画像表示装置として構成する場合の作用効果を説明する。視線射出手段を光学系近傍に配置することより、観察者の視線を射出することが可能となっている。ここで、視線射出について、図5、図6を用いて説明する。図5 (a) は光軸に対して偏心した3つの面3、4、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心フリスム12と画像表示素子7からなる画像表示装置の断面図、図5 (b) は光軸に対して偏心した4つの面3、4、5、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心フリスム12と画像表示素子7からなる画像表示装置の断面図であり、また、図6は光軸に対して偏心した4つの面3、4、5、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心フリスム12と画像表示素子7からなる画像表示装置の断面図であり、また、図6は光軸に対して偏心した4つの面3、4、5、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心フリスム12と画像表示素子7からなる画像表示装置の断面図であり、図中、1は観察者の眼、2は観察者視線、3は接眼光学系12の第1面、4は第2面、5は第3面、6は第4面、7は画像表示素子、9は視線射出手段、10は視線射出手段、11は照明手段、12は接眼光学系、15は観察者領域である。

【0072】図5 (a) は、接眼光学系12の偏心フリスムを抜き、観察者領域15と対向する外側面に視線射出手段9、10を配置した図である。この場合、観察者領域1の像は、観察者領域1の直前に配置した第1面3と、接眼光学系12の外側に配置してある反射面である第2面4とを透過して視線射出手段9、10に射入する必要がある。しかし、接眼光学系12の外側に配置してある第2面4は、反射面なので反射コーティングが施されておらず、視線射出手段9、10に観察者領域1の像を導くためには、反射面に反射コーティングしない部分NC (コーティング穴) が必要であり、観察する画像に歪みを生ずることになる。

【0073】図5 (b)、図6に本発明の像観察装置で

ある画像表示装置を示す。接眼光学系12の外側に配置してある反射面である第3面5が一部全反射するように形成されている。その全反射面外は、反射コーティングがなくても画像表示素子7からの光を反射するため反射コーティングが不要になり、観察者領域1の像は、観察者領域1の直前に配置した第1面3と接眼光学系12の外側に配置してある第3面5の全反射部分とを透過して視線射出手段9、10によって射出することができる。したがって、接眼光学系12の反射面に電子像の観察に悪影響をおよぼすコーティング穴を作成することなく、視線射出ができる。

【0074】この場合、偏心フリスムの第1面は全反射作用を有することが望ましい。その場合、視線射出手段は、第2面又は第3面の全反射領域を透過して観察者の視線を射出する位置に配置されていることが望ましい。

【0075】また、観察者領域を照明する照明手段を有することが望ましい。この画像表示装置は、観察者領域を照明することにより明るい像を射出できるため、観察者の正確な視線が射出可能である。また、照明手段は接眼光学系12の外側に配置されていることが望ましい。図5 (a) のように、観察者領域と接眼光学系12の間の配向され、観察者領域と干渉する危険が生じる。しかしながら、図5 (b) のように、照明手段11を接眼光学系12の外側に配置すると、観察者領域との干渉を避けて配置することができる。さらに、照明手段11からの照明光を接眼光学系12の反対面の全反射部分と透過するように配置することによって、コーティング穴を作成することなく観察者領域を照明することが望ましい。照明手段は赤外光を用いるものであること望ましい。電

子線を観察することは、即観察者領域が画像表示素子の光によって照明されていることとなる。角反射法等の装置を画像表示素子7の必要のある視線射出手段においては、斜々と照射光線の変化する画像表示素子の光線による反射像を排除する必要がある。通常、画像表示素子はLCD等であり、放射する光は可視域の波長域である。したがって、照明手段は赤外光を用いることと、画像表示素子からの光による影響を低減することとができる。

【0076】そして、この場合も、接眼光学系と像形成手段と接眼光学系を観察者領域に対して位置決めする位置決め手段を有することとができる。

【0077】また、以上の像観察装置において、像形成手段と接眼光学系を観察者領域に対して位置決めする位置決め手段を有することとができる。

【0078】さらに、このような像観察装置の少なくとも2組を一定の間隔で支持する支持手段を設けて両眼で立体像等を観察可能にすることができ、

表示素子と、前記画像表示素子により形成された画像を画像として露でるように書く接眼光学系とを有する画像表示装置において、前記接眼光学系は少なくとも2面と形成される空間を屈折率が1より大きい媒質で満たされており、観察者領域直前に位置している第1面と、前記第1面に対向した反射面である第2面のうち、少なくとも1面が、観察者視線に対して偏心であるいは傾いた面と構成された偏心フリスムと、前記第2面の外側に配置され、外界光に対して前記第1面と前記第2面とで発生する偏心による収差の補正作用を有する収差補正手段とを含んだ構成を有することを特徴とするものである。

【0080】この画像表示装置においては、観察者領域直前に位置している第1面と、第1面に対向した反射面である第2面を介して外界像を観察する場合、この2面の中少なくとも1面は観察者視線に対して偏心あるいは傾いた面であるため、光軸に非対称な偏ったパワ－を有するレンズを通して外界を観察しているのと同様になる。そこで、第2面の外側に偏ったパワ－を打ち消すようなフレネルレンズ等の収差補正手段を配置することにより、観察者はより自然な外界を観察することが可能となる。さらに、フレネルレンズは非偏り偏り光学素子なので、装置を大きくすることなく小型な画像表示装置を提供できる。

【0081】また、本発明において、フレネルレンズは上述した効果を得られるならは他の光学素子、例えば、回折光学素子、ホログラフィック光学素子等に置き換えてもよい。

【0082】なお、フレネルレンズを用いる場合、フレネルレンズの輪郭の中心が、前記画像表示素子からの軸上主光線の光路を含む面内にあり、フレネルレンズが軸上主光線の光路を含む面内において視線に対して垂直に偏心していることが望ましい。フレネルレンズは軸対称の形状であれば、製作性に優れ、コストも低くできる。軸対称のパワ－を有するフレネルレンズを軸上主光線の光路を含む面内において視線に対して偏心させて配置することによって、外界光に対して第1面と第2面で発生する偏心による収差をより良好に補正することが可能になる。さらに、観察者に対する突出量や、接眼光学系とフレネルレンズの間の空間が狭く、無駄のな



11

い非常にコンパクトな画像表示装置を提供することができ、

【0084】本発明のもう1つの画像形成装置は、画像表示素子と、前記画像表示素子により形成された画像を画像として観察できるように導く接眼光学系とを有する画像表示装置において、前記接眼光学系は、少なくとも3面で形成される空間を屈折率が1より大きい媒質で満たしており、前記少なくとも3面は、観察者眼球直前に位置している屈折及び内部反射面と、前記屈折及び内部反射面に対向し前記接眼光学系の外側に配置された外側内部反射面と、前記画像表示素子の発する光束を入射する屈折面とからなり、その中の少なくとも1面が、観察者視線に対して傾くあるいは傾いた面で構成され、少なくとも3回の内部反射をしている偏心プリズムと、前記観察者眼球直前に位置している屈折及び内部反射面と前記外側内部反射面とを介して外界を観察する場合、外界光に対して前記2面で発生するパワーを打ち消す作用を有する第2光学素子とからなり、前記第2光学素子は前記外側内部反射面の外側に配置されていることを特徴とするものである。

【0085】観察者眼球直前に位置している第1面と、第1面に対向した反射面である第2面を介して外界を観察する場合、この2面の中少なくとも1面は観察者視線に対して傾くあるいは傾いた面であるため、各領域によって異なる傾いたパワーを有するレンズを通して外界を観察していると同様になる。そこで、外界光に対して上記の2面で発生する傾いたパワーを打ち消す作用を有する第2光学素子を接眼光学系の外側に配置することにより、観察者はより自然で危険防止と緊急時対応ができ、安全な画像表示装置を提供することができる。

【0086】この場合、接眼光学系は、4面で形成される空間を屈折率が1より大きい媒質で満たされ、その4面は、観察者眼球側に位置している屈折面かつ反射面である第1面、第1面に対向した反射面である第2面、第1面に対向し第2面に隣接した反射面である第3面、面像表示素子に最も近接している屈折面である第4面で構成され、少なくとも1面が観察者視線に対して傾くあるいは傾いた面を含む偏心プリズムからなっているもよい。接眼光学系がこのように4面で構成されている場合、第1面と第2面を透過した外界光によって外界を認識する。その場合、第2面を透過する領域においてのみ傾いたパワーを打ち消す作用を有する第2光学素子を配置することで、接眼光学系全体は大幅にサイズを削減することが可能となる。

【0087】また、第1面と第2面と第2光学素子、若しくは、第1面と第3面と第2光学素子を介して外界を観察できるように、少なくとも1つの第2光学素子を第2面又は第3面の外側に配置することが望ましい。第2面の外側に傾いたパワーを打ち消す作用を有する第

(11)

特開平10-307263

10

2光学素子を配置することで、電子像を観察する領域と周囲に領域において自然な外界を観察することができ、また、同様、第3面の外側に傾いたパワーを打ち消す作用を有する第2光学素子を配置することにより電子像とは異なる領域においても自然な外界を観察できる。さらに、2つの第2光学素子を同時に第2面と第3面の外側に配置することにより、観察者は第1面と第2面及び第1面と第3面を透過する外界像を全て観察することができる。したがって、電子像の観察面よりも外界観察面の方が広がり、自然で危険防止と緊急時の適切な対応ができ、非常に安全な画像表示装置を提供することができる。

【0088】また、第2光学素子は、外界光に対する第1面と第2面、若しくは、第1面と第3面のそれぞれの合成パワーを同時に打ち消す作用を有することが望ましい。外界光に対する第1面と第2面、第1面と第3面のそれぞれの合成パワーを同時に打ち消す作用を有する第2光学素子を1つの光学素子で構成し、接眼光学系の外側に配置することで広範囲の外界を観察できる。この第2光学素子は同時にそれぞれの合成パワーを打ち消すので、外界側に切れ目が入らずより自然に観察ができる。したがって、1個の光学素子で広い範囲の外界を認識でき、コスト的にも安価で危険防止と緊急時対応ができ、安全な望みそう高まった画像表示装置を提供することができ、

【0089】また、以上において、画像表示素子と接眼光学系を観察者頭部に対して位置決めする位置決め手段を有するようにすることができ、画像表示素子と接眼光学系を観察者頭部に対して位置決めする位置決め手段を有することにより、観察者は安定した電子像を観察することが可能となる。

【0090】また、画像表示素子と接眼光学系を観察者頭部に対して支持する支持手段を有し、観察者頭部に装着できるようにすることができ、画像表示素子と接眼光学系を観察者頭部に対して支持する支持手段を有し、観察者頭部に装着できるようにしたことによって、観察者は自由な観察姿勢や、観察方向で電子像を観察することが可能となる。

【0091】さらに、画像表示装置の少なくとも2個を一定の間隔で支持する支持手段を有するようにすることもできる。少なくとも2個を一定の間隔で支持する支持手段を有することによって、観察者は左右両眼で像を観察することが可能となる。また、左右の電子像に視差を与えた画像を表示し、両眼でそれらを観察することによって立体像を感知することが可能となる。

【0092】また、以上の画像表示装置における接眼光学系を接眼光学系として用いることが可能である。接眼光学系における画像表示面を像面として、無限遠の物体を結像させるように構成すること、図24に示すよう

11

(11)

特開平10-307263

なカメラのフラインダー光学系等の結像光学系として利用することが可能である。

【0093】なお、本発明において、第2面と第3面とを同一面にて兼用させることができる。その場合、物理的な面の数を1面減少させることができるため、光学設計上及び、プリズムの生産上、工程が簡略化でき、量産性に優れた価格の低廉に寄与できる。さらに、物理的に1つの面に第2面作用と第3面作用とを併せ持つように兼用させ、かつ、光束が内部反射する領域の一部オーバーラップさせるようにすれば、プリズム部材の小型化が実現でき望ましい。

【0094】以下に、本発明による画像表示装置の実施例1〜17について説明する。後述する各実施例の構成パラメータにおいては、代表的に図1に示すように、接眼光学系12の射出瞳1を光学系の原点として、光軸2を画像表示素子7の表示中心と射出瞳1の中心(原点)とを通る光線で定義し、射出瞳1から光軸2の進む方向をZ軸方向、このZ軸に直交し射出瞳1中心を通り、光軸が接眼光学系12によって折曲げられる案内の方向をY軸方向、Z軸、Y軸に直交し射出瞳1中心を通る方向をX軸方向とし、射出瞳1から接眼表示素子7に向かう方向をZ軸の正方向、光軸2から画像表示素子7方向をY軸の正方向、そして、これらZ軸、Y軸と右手系を構成する方向をX軸の正方向とする。なお、光線追跡は接眼光学系12の射出瞳1の側を物体側として、画像表示素子7側を像側とした逆光線追跡により行っている。

【0095】そして、偏心量Y、Z、傾き角θが記載されている面については、構成パラメータ中に特に記載のない限り(実施例6、9には記載あり)、光学系の原点である射出瞳1からのY方向、Z方向へのずれ量及び面の中心軸のZ軸に対する傾き角を表している。なお、傾き角は反時計回りの方向を正としている。また、凸曲面を得に記載している場合は、その凸曲面の面傾からの同様のずれ量及び傾き角を表している。

【0096】また、後述する構成パラメータ中に、同軸部分の曲率半径、材質の屈折率、フッベ数を適用法に従って示している。

【0097】図1〜図4、図5(b)、図17は本発明の実施例1〜4、5〜17の画像表示装置の光軸を含む断面図であり、図1〜図4、図5(b)、図11、図15〜図16の実施例においては、光軸に対して傾いた4つの面、4、5、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心プリズム12で埋められ、また、図17の実施例においては、光軸に対して傾いた3つの面3、4、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心プリズム12からなる。各図中、1は観察者の眼、

11

11

特開平10-307263

2は観察者角膜、3は接眼光学系12の第1面、4は第2面、5は第3面、6は第4面、7は画像表示素子、8はフレイネルレンズ、9は投映射出光学系、10は投映射出素子、11は照明手段、12は接眼光学系(偏心プリズム)、13、14は第2光学素子、15は観察者領域、16は光学ファイバー、17はリアモーター、18は光素子に設けられた窓部、19は外装部に設けられたガイド(ルーラー)であり、電子像を観察する場合の実際の光線経路は、図1〜図4、図5(b)、図11、図15〜図16の実施例においては、画像表示素子7の電子像から発した光線は、接眼光学系12の画像表示素子7と対面している屈折面である第4面6に入射し、観察者頭部の反対側に位置する第2面4、5の中、第4面6に隣接する第3面5で観察者瞳1側に反射し、観察者瞳1の直前に配置している第1面3で観察者瞳1から遠ざかる方向に反射し、観察者頭部の反対側に位置している第2面4、5の中、観察者瞳1の直前に配置している第2面4で観察者瞳1側に反射をし、第1面3を透過して観察者の虹彩位置又は虹膜の位置中心を射出瞳1として観察者の眼球15内に投影される。また、図17の実施例17においては、画像表示素子7の電子像から発した光線

は、接眼光学系12の画像表示素子7と対面している屈折面である第4面6に入射し、観察者頭部の反対側に位置する第3面5を穿用した第2面4の第4面6に隣接する領域(第3面5)で観察者瞳1側に反射し、観察者瞳1の直前に配置している第1面3で観察者瞳1から遠ざかる方向に反射し、観察者頭部の反対側に位置している第4面6から遠い領域で観察者瞳1側に反射をし、第1面3を透過して観察者の虹彩位置又は虹膜の位置中心を射出瞳1として観察者の眼球15内に投影される。

【0098】図5(b)、図6に示したものは、投映射出手段を有する本発明の画像表示装置の実施例である。接眼光学系12の外側に配置してある反射面である第3面5が一部全反射するように設定されている。その全反射部分は、反射コーティングなしであっても画像表示素子7からの光を反射するため反射コーティングが不要になり、また、投映射出する場合の光束の光線経路は、光線11からの照明光は、接眼光学系12の第3面5と第1面3を透過して観察者瞳15を照明し、そこで反射した光線が観察者瞳1の直前に配置してある第1面3に入射し、観察者頭部の反対側に位置する第3面5の少なくとも一部を全反射している領域を透過して投映射出用光学系9により投映射出器10に導かれ、観察者瞳1の像を形成する。ここで、電子像等の光による影響を低減するため、赤外光の照明11や、赤外光を射出する投映器10を用いても当らない。さらに、照明手段11の位置は、図示した場所であっても構わない。

【0099】また、図18は、実施例17のように光軸に対して傾いた3つの面3、4、6からなる接眼光学

系12の場合に、投鏡映出用光学系9、投鏡映出器10、光源11からなる同様な投鏡映出手段を設けた場合の断面図である。投鏡映出する場合の実際の光線経路は、図5(b)、図6と同様であるので説明は省く。

[0100] 図7に示したものは、接眼光学系12によって電子像と外界像を同時に観察することが可能な本発明の実際の光線経路は、外界の物体からの光線が第3面5から入射し、第1面3を透過して、観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球内に投影される。さらに、第3面5の外界像に、外界光の光量を調節する減光フィルター若しくは光学系16を配置することにより、観察者が電子像、外界像の両方あるいは片方を観察しやすいようにすることも可能である。また、減光フィルターあるいは光学系16を観察範囲αとβとの間で移動可能にすることで、電子像、外界像の何れかのみを観察するようにすることができ、

[0101] 図8、図9に示したものは、接眼光学系12を移動することによって外界像を観察することができ、本発明の別の実際の光線経路の断面図である。図8では、図8(a)の電子像観察位置から接眼光学系12を観察者瞳1に対して前方(Y方向)に移動することにより、図8(b)の外野像観察位置となり、図9では、図9(a)の電子像観察位置から接眼光学系12を観察者瞳1に対して時計回りに回転することにより、図9(b)の外野像観察位置となり、図9(c)の外野像観察位置となる。したがって、何れも接眼光学系12を通して観察者の視線方向で外界を観察することが可能となる。外界の物体からの光線は、第3面5から入射し、第1面3を透過して観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球内に投影される。さらに、図8(b)において、観察者は、電子像を観察者視線2より下の領域で観察できる。ここで、電子像の観察方向は、接眼光学系12の配置の仕方や移動方向により異なるので如何なる方向でも構わない。

[0102] なお、図8(c)、図9(c)には、接眼光学系12の移動機構の例を示してある。何れの場合も、光学系12に設けられた突出部18を介してリニアモーター17により、接眼光学系12を外装部に設けられたガイド(ルーラー)19に沿って移動させればよい。図8(c)の場合はガイド(ルーラー)19が直線であり、図9(c)の場合はガイド(ルーラー)19が円弧であるので、それぞれ直線移動と回転が行われる。

[0103] なお、図19に、実際の例17のように光軸に対して偏心した3つの面3、4、6からなる接眼光学系12の場合に、図8の実際の例と同様に、電子像観察位置から接眼光学系12を観察者瞳1に対して前方(Y方向)に移動することにより外野像観察位置となる例を示してある。その作用は図8と同様であるので、説明は省く。

[0104] 図10～図14に示したものは、外界像を観察する光路中に収差補正手段であるフレネルレンズ8

を配置する本発明の実際の光線経路は、外界の物体からの光線は、フレネルレンズ8を透過して第2面4より偏心プリズムAに入射し、第1面3を透過して、観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球内に投影される。ここで、フレネルレンズ8は、外界を観察する場合に所定の位置に配置してあればよく、外界を観察しないときは上移動や回転移動等の移動機構によって別の位置に転換されるか、又は、取り外し可能に構成しても構わない。

[0105] 図10～図14中、図10～図11の場合には、図1等と同様に、接眼光学系1(偏心プリズム)12は光軸に対して偏心した4つの面3、4、5、6からなり、電子像観察時は同様の光線経路をたどるが、図12の偏心プリズムA12は、光軸に対して偏心した3つの面3、4、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心プリズムA12からなり、電子像を観察する場合の実際の光線経路は、画像表示素子7の電子像から発した光線は、接眼光学系12の画像表示素子7と対面している屈折面である第4面(偏心面)に配置してある第1面3で観察者瞳1から送らる方向に反射し、観察者側面の反対側に位置する第2面4で観察者瞳1側に反射をし、第1面3を透過して観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球15内に投影される。

[0106] また、図13の偏心プリズムA12は、光軸に対して偏心した3つの面3、4、6によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心プリズムA12からなり、電子像を観察する場合の実際の光線経路は、画像表示素子7の電子像から発した光線は、接眼光学系12の画像表示素子7と対面している屈折面である第4面(偏心面)に配置してある第2面4で観察者瞳1側に反射をし、第1面3を透過して観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球15内に投影される。

[0107] また、図14の偏心プリズムA12は、光軸に対して偏心した2つの面3、4によって形成された空間を屈折率が1より大きい媒質によって満たされた偏心プリズムA12からなり、電子像を観察する場合の実際の光線経路は、画像表示素子7の電子像から発した光線は、接眼光学系12の画像表示素子7と対面している屈折面である第1面3に入射し、観察者側面の反対側に位置する第2面4で観察者瞳1側に反射をし、第1面3を透過して観察者の虹彩位置又は眼球の回折中心を射出瞳1として観察者の眼球15内に投影される。

[0108] 次に、図15、図16に示したものは、外界像を観察する光路中に接眼光学系12の観察者視線直前に位置している第1面3と外界側内面反射面である第

2面4又は第3面5とを介して外界を観察する場合、外界光に対してその2面3、4又は3、5で発生するパワースプレッド作用を有する第2光学系13、14を配置する本発明の実際の光線経路は、外界の物体からの光線は、第2光学系13あるいは別の第3光学系14を透過して、第2面4あるいは第3面5から偏心プリズムA12に入射し、第1面3を透過して観察者の虹彩位置

※又は眼球の回折中心を射出瞳1として観察者の眼球内に投影される。  
[0109] なお、本発明は図1～図4、図5(b)～図19の光学系に形成されるものではなく、公知のその他の光学系に適用できるものである。  
[0110] 以下の各図例の構成パラメータ中、回転対称な非球面形状は、近軸曲率半径をRとすると、次の式で与えられる。Z軸の回転対称な非球面の軸となる。  
$$Z = (h^2 / R) / [1 + \{1 - (1 + K) (h^2 / R^2)^{1/2}\}]$$
  
$$+ Ah^4 + Bh^6 + Ch^8 + Dh^{10} \dots$$
  
$$(h^2 = x^2 + y^2)$$

ただし、Zは面形状の原点に対する接平面からのずれ量、Kは円錐係数、A、B、C、Dはそれぞれ4次、6次、8次、10次の非球面係数である。  
$$Z = (CX \cdot x^2 + CY \cdot y^2) / [1 + \{1 - (1 + K_1) CX^2 \cdot x^2 - (1 + K_2) CY^2 \cdot y^2\}^{1/2}]$$

例として、m=4(4次項)までを考えると、展開したときに以下の式で表される。  
$$Z = (CX \cdot x^2 + CY \cdot y^2) / [1 + \{1 - (1 + K_1) CX^2 \cdot x^2 - (1 + K_2) CY^2 \cdot y^2\}^{1/2}]$$

★  
$$= (1 + K_1) CX^2 \cdot x^2 + (1 + K_2) CY^2 \cdot y^2 + \dots$$
  
$$R_1: \{(1 - P_1) x^2 + (1 + P_1) y^2\}^{1/2}$$
  
$$R_2: \{(1 - P_2) x^2 + (1 + P_2) y^2\}^{1/2}$$
  
$$R_3: \{(1 - P_3) x^2 + (1 + P_3) y^2\}^{1/2}$$
  
$$R_4: \{(1 - P_4) x^2 + (1 + P_4) y^2\}^{1/2}$$

ただし、Zは面形状の原点に対する接平面からのずれ量、CXはX軸方向曲率、CYはY軸方向曲率、K<sub>1</sub>はX軸方向円錐係数、K<sub>2</sub>はY軸方向円錐係数、P<sub>1</sub>は非球面回転対称成分、P<sub>2</sub>は非球面回転非対称成分である。なお、後記する実際の例の構成パラメータでは、  
R<sub>1</sub>: X軸方向曲率半径  
R<sub>2</sub>: Y軸方向曲率半径  
R<sub>3</sub>: X軸方向曲率半径  
R<sub>4</sub>: Y軸方向曲率半径  
を用いており、曲率CX、CYとの間には、  
$$R_i = 1 / CX, R_j = 1 / CY$$

例として、k=7(7次項)を考えると、展開したときに以下の式で表される。  
[0114]

$$\begin{aligned} Z = & C_0 + C_1 Y + C_2 X \\ & + C_3 Y^2 + C_4 YX + C_5 X^2 \\ & + C_6 Y^3 + C_7 Y^2 X + C_8 XY^2 + C_9 X^3 \\ & + C_{10} Y^4 + C_{11} Y^3 X + C_{12} Y^2 X^2 + C_{13} YX^2 + C_{14} X^3 \\ & + C_{15} Y^5 + C_{16} Y^4 X + C_{17} Y^3 X^2 + C_{18} Y^2 X^2 + C_{19} YX^2 + C_{20} X^3 \\ & + C_{21} Y^6 + C_{22} Y^5 X + C_{23} Y^4 X^2 + C_{24} Y^3 X^2 + C_{25} Y^2 X^2 + C_{26} YX^2 + C_{27} X^3 \\ & + C_{28} Y^7 + C_{29} Y^6 X + C_{30} Y^5 X^2 + C_{31} Y^4 X^2 + C_{32} Y^3 X^2 + C_{33} Y^2 X^2 + C_{34} YX^2 + C_{35} X^3 \\ & + C_{36} Y^8 + C_{37} Y^7 X + C_{38} Y^6 X^2 + C_{39} Y^5 X^2 + C_{40} Y^4 X^2 + C_{41} Y^3 X^2 + C_{42} Y^2 X^2 + C_{43} YX^2 + C_{44} X^3 \\ & + C_{45} Y^9 + C_{46} Y^8 X + C_{47} Y^7 X^2 + C_{48} Y^6 X^2 + C_{49} Y^5 X^2 + C_{50} Y^4 X^2 + C_{51} Y^3 X^2 + C_{52} Y^2 X^2 + C_{53} YX^2 + C_{54} X^3 \\ & + C_{55} Y^{10} + C_{56} Y^9 X + C_{57} Y^8 X^2 + C_{58} Y^7 X^2 + C_{59} Y^6 X^2 + C_{60} Y^5 X^2 + C_{61} Y^4 X^2 + C_{62} Y^3 X^2 + C_{63} Y^2 X^2 + C_{64} YX^2 + C_{65} X^3 \end{aligned}$$





## 特開平10-307263

(17)

31  
 $C_1$   $3.6187 \times 10^{-3}$   $C_2$   $6.3763 \times 10^{-3}$   $C_3$   $-6.3771 \times 10^{-4}$   
 $C_{10}$   $5.0315 \times 10^{-4}$   $C_{11}$   $-5.7878 \times 10^{-4}$   $C_{12}$   $4.5123 \times 10^{-7}$   
 $C_{13}$   $-3.3885 \times 10^{-4}$   
 (1)  $\theta_{13} = 48.44^\circ$   
 (3)  $\phi_{11}$  ( $yz$ )  $= -0.0037$  (1/m)  
 $\phi_{11}$  ( $xz$ )  $= -0.0072$  (1/m)

[0120]

## 実施例3

面番号 曲率半径 間隔 屈折率  
(傾き角)

1  $\infty$  (面)  
 2  $\infty$   
 (1ST SF) Y  $-37.000$   $\theta$   $0.00^\circ$   
 Z  $37.335$

3 ANAM  $R_2$   $-143.313$   
 (2ND SF)  $R_2$   $-133.233$  Y  $-14.883$   $\theta$   $-26.30^\circ$   
 (REFL)  $K_2$   $0.3713$  Z  $42.871$   
 $K_2$   $-1.3842$

$R_1$   $2.1403 \times 10^{-4}$   
 $R_2$   $1.4413 \times 10^{-13}$   
 $R_3$   $6.3686 \times 10^{-14}$   
 $R_4$   $-1.2452 \times 10^{-17}$   
 $P_1$   $-3.1888 \times 10^{-3}$   
 $P_2$   $-3.0413$   
 $P_3$   $2.5877 \times 10^{-1}$   
 $P_4$   $4.2610 \times 10^{-1}$

4 (1ST SF) Y  $1.5354$   $\theta$   $56.25^\circ$   
 (REFL) Z  $37.335$

5  $\infty$   
 (32D SF) Y  $0.074$   $\theta$   $0.00^\circ$   
 Z  $53.531$

6 ANAM  $R_2$   $38.861$  Y  $44.488$   $\theta$   $-16.77^\circ$   
 (4TH SF)  $R_2$   $62.319$  Z  $51.046$   
 $K_2$   $1.5354$

$K_2$   $4.2435$   
 $R_1$   $3.1084 \times 10^{-4}$   
 $R_2$   $5.0510 \times 10^{-10}$   
 $R_3$   $4.1921 \times 10^{-13}$   
 $R_4$   $-6.4158 \times 10^{-15}$   
 $P_1$   $-1.5408 \times 10^{-1}$   
 $P_2$   $4.0173$   
 $P_3$   $1.4631$   
 $P_4$   $1.0506$

7  $\infty$   
 (面像表示面) Y  $42.800$   $\theta$   $-21.40^\circ$   
 Z  $38.475$

(1)  $\theta_{13} = 44.53^\circ$   
 (3)  $\phi_{11}$  ( $yz$ )  $= 0$  (1/m)  
 $\phi_{11}$  ( $xz$ )  $= 0$  (1/m)

[0121]

## 特開平10-307263

(18)

33

実施例4  
 面番号 曲率半径 間隔 屈折率  
(傾き角)

1  $\infty$  (面)  
 2 ANAM  $R_2$   $-142.348$  Y  $1.5354$   $\theta$   $56.25^\circ$   
 (1ST SF)  $R_2$   $-159.716$  Z  $37.335$   
 $K_2$   $12.1104$

$K_2$   $4.7358$   
 $R_1$   $-2.5719 \times 10^{-10}$   
 $R_2$   $-4.3732 \times 10^{-12}$   
 $R_3$   $6.8615 \times 10^{-13}$   
 $R_4$   $6.7191 \times 10^{-10}$   
 $P_1$   $-1.8150 \times 10^{-1}$   
 $P_2$   $-4.7838$   
 $P_3$   $-1.2178$   
 $P_4$   $-7.1384$   
 3 ANAM  $R_2$   $-119.582$  Y  $1.5354$   $\theta$   $56.25^\circ$   
 (2ND SF)  $R_2$   $-10.451$  Z  $37.335$   
 (REFL)  $K_2$   $-0.1181$   
 $K_2$   $0.7816$

$R_1$   $-1.6818 \times 10^{-4}$   
 $R_2$   $-1.2248 \times 10^{-11}$   
 $R_3$   $6.5659 \times 10^{-10}$   
 $R_4$   $6.0116 \times 10^{-14}$   
 $P_1$   $-1.8331$   
 $P_2$   $-4.1728 \times 10^{-1}$   
 $P_3$   $-2.3104$   
 $P_4$   $-1.6450 \times 10^{-1}$

4 ANAM  $R_2$   $-242.348$  Y  $1.5354$   $\theta$   $56.25^\circ$   
 (1ST SF)  $R_2$   $-159.716$  Z  $37.335$   
 (REFL)  $K_2$   $12.1104$

$K_2$   $4.7358$   
 $R_1$   $-2.5719 \times 10^{-10}$   
 $R_2$   $-4.3732 \times 10^{-12}$   
 $R_3$   $6.8615 \times 10^{-13}$   
 $R_4$   $6.7191 \times 10^{-10}$   
 $P_1$   $-1.8150 \times 10^{-1}$   
 $P_2$   $-4.7838$   
 $P_3$   $-1.2178$   
 $P_4$   $-7.1384$   
 5 ANAM  $R_2$   $-179.007$  Y  $1.5354$   $\theta$   $56.25^\circ$   
 (32D SF)  $R_2$   $-231.111$  Z  $37.335$   
 (REFL)  $K_2$   $3.2268$   
 $K_2$   $-72.7188$

$R_1$   $6.1312 \times 10^{-4}$   
 $R_2$   $-1.4470 \times 10^{-13}$   
 $R_3$   $2.8044 \times 10^{-15}$   
 $R_4$   $1.0069 \times 10^{-14}$   
 $P_1$   $2.0705 \times 10^{-1}$

34

(11)

特開平10-307263

35

36

35	P <sub>1</sub>	1.7167		
	P <sub>2</sub>	-5.5003		
	P <sub>3</sub>	-4.0534		
6 ANAM	R <sub>1</sub>	72.213	Y	42.321 $\theta$ -41.34°
(4TH SF)	R <sub>2</sub>	39.167	Z	43.324
	K <sub>1</sub>	-1.0213		
	K <sub>2</sub>	-1.3305		
	R <sub>1</sub>	-7.5404 $\times 10^{-7}$		
	R <sub>2</sub>	-5.8510 $\times 10^{-10}$		
	R <sub>3</sub>	5.3345 $\times 10^{-13}$		
	R <sub>4</sub>	1.5191 $\times 10^{-16}$		
	P <sub>1</sub>	-1.1077 $\times 10^{-1}$		
	P <sub>2</sub>	2.1174 $\times 10^{-3}$		
	P <sub>3</sub>	2.2120 $\times 10^{-1}$		
	P <sub>4</sub>	-1.4511		
7		$\infty$	Y	42.878 $\theta$ -18.31°
(面像表示面)			Z	30.211

(1)  $\theta_{12}=42.75^\circ$   
 (3)  $\phi_{11}(\gamma z)=0.008$  (1/mm)  
 $\phi_{11}(\kappa z)=-0.001$  (1/mm)

[01222]

実施例5

面番号 曲率半径 間隔

屈折率  
(偏心率)アッペ散  
(傾き角)

1		$\infty$ (偏)		
2		-104.851		
(1ST SF)			Y	1.5254 $\theta$ -7.07°
	Y	2.540	Z	33.527
3 ANAM	R <sub>1</sub>	-54.751		
(2ND SF)	R <sub>2</sub>	-42.006	Y	1.5254 $\theta$ -18.747 $\theta$ -48.21°
(3EFL)	K <sub>1</sub>	-1.3814	Z	30.185
	K <sub>2</sub>	0.1844		
	R <sub>1</sub>	2.4430 $\times 10^{-10}$		
	R <sub>2</sub>	-1.1183 $\times 10^{-10}$		
	R <sub>3</sub>	-2.4832 $\times 10^{-16}$		
	R <sub>4</sub>	1.3034 $\times 10^{-12}$		
	P <sub>1</sub>	-2.7674 $\times 10^{-1}$		
	P <sub>2</sub>	5.3845 $\times 10^{-1}$		
	P <sub>3</sub>	-4.1448		
	P <sub>4</sub>	1.0048 $\times 10^{-1}$		
4		-104.851		
(1ST SF)			Y	1.5254 $\theta$ -7.07°
(3EFL)	K <sub>1</sub>	0.1844	Z	33.527
5 ANAM	R <sub>1</sub>	-8201.135		
(3RD SF)	R <sub>2</sub>	1243.857	Y	1.5254 $\theta$ -18.747 $\theta$ -48.21°
(3EFL)	K <sub>1</sub>	0.0000	Z	33.061
	K <sub>2</sub>	0.0000		
	R <sub>1</sub>	8.7227 $\times 10^{-8}$		
	R <sub>2</sub>	1.2246 $\times 10^{-12}$		
	R <sub>3</sub>	-1.5958 $\times 10^{-10}$		

(12)

特開平10-307263

37

38

37	R <sub>1</sub>	1.7177 $\times 10^{-11}$		
	P <sub>1</sub>	8.5858 $\times 10^{-1}$		
	P <sub>2</sub>	-4.4464		
	P <sub>3</sub>	1.1191		
	P <sub>4</sub>	2.2011		
6		46.674	Y	20.180 $\theta$ -21.11°
		$\infty$	Y	31.793 $\theta$
7		-16.07°		
(面像表示面)			Z	35.135
(1) $\theta_{12}=36.51^\circ$				

[01231]

実施例6

面番号 曲率半径 間隔

屈折率  
(偏心率)アッペ散  
(傾き角)

1		$\infty$ (偏)		
2		$\infty$	Y	0.000 $\theta$ 20.00°
(仮組面)			Z	0.000
3		$\infty$		
(1ST SF)			Y	1.5254 $\theta$ 56.25
	Y	0.000	Z	40.435
4 ANAM	R <sub>1</sub>	-144.461		
(2ND SF)	R <sub>2</sub>	-131.047	Y	1.5254 $\theta$ 56.25
(3EFL)	K <sub>1</sub>	-0.1158	Y	-21.096 $\theta$ -21.35°
	K <sub>2</sub>	-0.8570	Z	49.040
	R <sub>1</sub>	1.4710 $\times 10^{-8}$		
	R <sub>2</sub>	2.4181 $\times 10^{-10}$		
	R <sub>3</sub>	8.0445 $\times 10^{-14}$		
	R <sub>4</sub>	-1.0555 $\times 10^{-16}$		
	P <sub>1</sub>	-6.7918 $\times 10^{-1}$		
	P <sub>2</sub>	1.1524 $\times 10^{-2}$		
	P <sub>3</sub>	9.6151 $\times 10^{-1}$		
	P <sub>4</sub>	5.4280 $\times 10^{-1}$		
5		$\infty$		
(1ST SF)			Y	1.5254 $\theta$ 56.25
(3EFL)	K <sub>1</sub>	0.1158	Y	0.000 $\theta$ 0.00°
6		$\infty$	Z	40.435
(3RD SF)				
(3EFL)	K <sub>1</sub>	0.1158	Y	1.5254 $\theta$ 56.25
7 ANAM	R <sub>1</sub>	70.861		
(4TH SF)	R <sub>2</sub>	39.816	Y	1.5254 $\theta$ 56.25
	K <sub>1</sub>	1.0468	Z	43.245
	K <sub>2</sub>	1.1381		
	R <sub>1</sub>	1.0385 $\times 10^{-4}$		
	R <sub>2</sub>	1.6449 $\times 10^{-10}$		
	R <sub>3</sub>	-2.4116 $\times 10^{-12}$		
	R <sub>4</sub>	-7.2767 $\times 10^{-15}$		
	P <sub>1</sub>	3.2623 $\times 10^{-1}$		

40

- 31  
 $P_2$  3.4157  
 $P_3$   $1.0101 \times 10^{-1}$   
 $P_4$   $1.1138 \times 10^{-1}$   
 $\infty$   
 (画像表示面)  
 (1)  $\theta_{rs} = 4.6, 7.0^\circ$   
 (3)  $\phi_{rs} (yz) = 0 (1/\text{mm})$   
 $\phi_{rs} (xz) = 0 (1/\text{mm})$

Y 40.134  $\theta$  -2.11°  
 Z 30.403

【0.124】

実施例9  
 面番号 曲率半径 間隔 屈折率 (屈折率) ツッペ数 (傾き角)

- 1  $\infty$  (屈) Y 0.000  $\theta$  15.00°  
 2  $\infty$  Z 0.000  
 (仮想面) 1.5354 51.35  
 (仮想面から) Y 0.000  $\theta$  0.00°  
 3 (IST SF) Z 38.879  
 4 -101.403 1.5354 51.35  
 (2ND SF) (仮想面から) Y -11.310  $\theta$  -30.81°  
 (REFL) Z 48.157  
 5 -221.433 1.5354 51.35  
 (IST SF) (仮想面から) Y 0.000  $\theta$  0.00°  
 (REFL) Z 38.879  
 6 -101.403 1.5354 51.35  
 (3RD SF) (仮想面から) Y 0.000  $\theta$  0.00°  
 (REFL) Z 55.417  
 7 154.185 (仮想面から) Y 22.033  $\theta$  -10.71°  
 (4TH SF) Z 41.581  
 8  $\infty$  Y 38.534  $\theta$  -5.00°  
 (画像表示面) Z 27.732  
 (1)  $\theta_{rs} = 4.1, 6.8^\circ$   
 (3)  $\phi_{rs} (yz) = 0, 0.0024 (1/\text{mm})$   
 $\phi_{rs} (xz) = 0, 0.0024 (1/\text{mm})$

【0.125】

実施例10  
 面号 曲率半径 間隔 屈折率 (屈折率) ツッペ数 (傾き角)

- 1  $\infty$  (屈) 1.5354 51.35  
 2 -104.451 Y 2.540  $\theta$  -7.07°  
 (IST SF) Z 33.537  
 3 ANAM R<sub>r</sub> -54.751 Y -13.747  $\theta$  -48.21°  
 (2ND SF) R<sub>s</sub> -12.006 Z 30.187  
 (REFL) K<sub>r</sub> -1.3114

41

- 41  
 $K_x$  0.1844  
 $R_1$   $1.4430 \times 10^{-10}$   
 $R_2$   $-1.1189 \times 10^{-10}$   
 $R_3$   $-2.4882 \times 10^{-10}$   
 $R_4$   $1.0084 \times 10^{-10}$   
 $P_1$   $-2.7174 \times 10^{-1}$   
 $P_2$   $5.3845 \times 10^{-1}$   
 $P_3$   $-4.1418$   
 $P_4$   $1.0048 \times 10^{-1}$

4 (ツレネルレンズ第1面) 2.000 1.4922 57.50  
 Y 45.000  $\theta$  0.00°  
 Z 53.537

【0.126】

実施例11  
 面番号 曲率半径 間隔 屈折率 (屈折率) ツッペ数 (傾き角)

- 1  $\infty$  (屈) 1.5354 51.35  
 2 -104.451 Y 2.540  $\theta$  -7.07°  
 (IST SF) Z 33.537  
 3 ANAM R<sub>r</sub> -54.751 Y -13.747  $\theta$  -48.21°  
 (2ND SF) R<sub>s</sub> -12.006 Z 30.187  
 (REFL) K<sub>r</sub> -1.3114  
 $K_x$  0.1844  
 $R_1$   $1.4430 \times 10^{-10}$   
 $R_2$   $-1.1189 \times 10^{-10}$   
 $R_3$   $-2.4882 \times 10^{-10}$   
 $R_4$   $1.0084 \times 10^{-10}$   
 $P_1$   $-2.7174 \times 10^{-1}$   
 $P_2$   $5.3845 \times 10^{-1}$   
 $P_3$   $-4.1418$   
 $P_4$   $1.0048 \times 10^{-1}$

4 (ツレネルレンズ第1面) 2.000 1.4922 57.50  
 Y 45.000  $\theta$  -12.00°  
 Z 53.537

5 (ツレネルレンズ第2面)  $\infty$

- K 0.0000  
 $A$   $4.4111 \times 10^{-4}$   
 $B$   $-1.0534 \times 10^{-2}$   
 $C$   $1.1648 \times 10^{-10}$   
 $D$   $-4.3418 \times 10^{-14}$

【0.127】

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## 実施例12 (1)

面番号	曲率半径	間隔	屈折率 (偏心率)	アッペ数 (傾き角)
1	$\infty$ (面)		1.5154	51.15°
2	自由曲面① (1ST SF)		Y 13.403 $\theta$ 1.41° Z 33.974	
3	自由曲面② (2ND SF)		Y 4.516 $\theta$ -15.23° Z 41.231	
4	自由曲面③ (3RD SF)		Y 13.363 $\theta$ 1.41° Z 33.974	
5	自由曲面④ (4TH SF)		Y 27.094 $\theta$ 71.31° Z 35.215	
6	$\infty$ (面像表示面)		Y 11.216 $\theta$ 41.31° Z 41.316	

$C_1$ -1.1152 $\times 10^{-3}$	$C_7$ -3.1705 $\times 10^{-3}$	$C_9$ -7.5434 $\times 10^{-4}$
$C_{10}$ -1.5120 $\times 10^{-4}$	$C_{12}$ 1.1572 $\times 10^{-7}$	$C_{14}$ 1.3359 $\times 10^{-4}$
$C_{15}$ 1.7141 $\times 10^{-7}$	$C_{17}$ -2.1881 $\times 10^{-4}$	$C_{19}$ -3.0382 $\times 10^{-4}$
$C_{21}$ -2.0258 $\times 10^{-7}$	$C_{23}$ -3.8378 $\times 10^{-10}$	$C_{25}$ 1.4981 $\times 10^{-4}$
$C_{27}$ -3.8974 $\times 10^{-4}$	$C_{29}$ -2.5335 $\times 10^{-4}$	$C_{30}$ 4.3101 $\times 10^{-11}$
$C_{31}$ -1.4933 $\times 10^{-11}$	$C_{33}$ 7.1024 $\times 10^{-11}$	$C_{34}$ -4.2410 $\times 10^{-11}$
$C_1$ -1.3334 $\times 10^{-3}$	$C_7$ -7.5944 $\times 10^{-3}$	$C_9$ -1.0105 $\times 10^{-4}$
$C_{10}$ 1.3371 $\times 10^{-4}$	$C_{12}$ 8.3881 $\times 10^{-7}$	$C_{14}$ -5.1811 $\times 10^{-7}$
$C_{15}$ -4.1104 $\times 10^{-7}$	$C_{17}$ -2.0403 $\times 10^{-10}$	$C_{19}$ -6.0184 $\times 10^{-4}$
$C_{21}$ -4.1181 $\times 10^{-4}$	$C_{23}$ 4.4143 $\times 10^{-10}$	$C_{25}$ 3.8170 $\times 10^{-10}$
$C_{27}$ 8.4970 $\times 10^{-11}$	$C_{29}$ -2.8001 $\times 10^{-10}$	$C_{30}$ 1.3164 $\times 10^{-12}$
$C_{31}$ -1.7177 $\times 10^{-10}$	$C_{33}$ 3.3220 $\times 10^{-11}$	$C_{34}$ 1.4101 $\times 10$

自由曲面⑤

$C_6$ -1.2118 $\times 10^{-3}$	$C_7$ -3.7012 $\times 10^{-3}$	$C_9$ -1.2210 $\times 10^{-4}$
$C_{10}$ 8.9713 $\times 10^{-4}$	$C_{12}$ -8.0741 $\times 10^{-4}$	$C_{14}$ -3.8333 $\times 10^{-4}$
$C_{15}$ 2.1881 $\times 10^{-4}$	$C_{17}$ -1.7720 $\times 10^{-4}$	$C_{19}$ -3.4143 $\times 10^{-4}$
$C_{21}$ -3.5310 $\times 10^{-7}$	$C_{23}$ 1.2185 $\times 10^{-7}$	$C_{25}$ 1.0013 $\times 10^{-7}$
$C_{27}$ 1.4833 $\times 10^{-7}$	$C_{29}$ -5.3531 $\times 10^{-4}$	

[0128]

## 実施例12 (2)

面番号	曲率半径	間隔	屈折率 (偏心率)	アッペ数 (傾き角)
1	$\infty$ (面)		1.5154	51.15°
2	自由曲面① (1ST SF)		Y 13.313 $\theta$ 1.41° Z 33.974	
3	自由曲面② (2ND SF)		Y 4.516 $\theta$ -15.23° Z 41.231	
4	$\infty$	1.000	1.4922	57.50°

## (ツレネルレンズ第1面)

Y 15.103  $\theta$  -18.17°  
Z 15.000

## 5 (ツレネルレンズ第2面)

$\infty$   
K 0.0000  
A 3.3372 $\times 10^{-4}$   
B -1.1171 $\times 10^{-4}$   
C 4.2377 $\times 10^{-13}$   
D -4.1831 $\times 10^{-17}$

$C_1$ -1.1152 $\times 10^{-3}$	$C_7$ -3.1705 $\times 10^{-3}$	$C_9$ -7.5434 $\times 10^{-4}$
$C_{10}$ -1.5120 $\times 10^{-4}$	$C_{12}$ 1.1572 $\times 10^{-7}$	$C_{14}$ 1.3359 $\times 10^{-4}$
$C_{15}$ 1.7141 $\times 10^{-7}$	$C_{17}$ -2.1881 $\times 10^{-4}$	$C_{19}$ -3.0382 $\times 10^{-4}$
$C_{21}$ -2.0258 $\times 10^{-7}$	$C_{23}$ -3.8378 $\times 10^{-10}$	$C_{25}$ 1.4981 $\times 10^{-4}$
$C_{27}$ -3.8974 $\times 10^{-4}$	$C_{29}$ -2.5335 $\times 10^{-4}$	$C_{30}$ 4.3101 $\times 10^{-11}$
$C_{31}$ -1.4933 $\times 10^{-11}$	$C_{33}$ 7.1024 $\times 10^{-11}$	$C_{34}$ -4.2410 $\times 10^{-11}$
$C_1$ -1.3544 $\times 10^{-3}$	$C_7$ -7.5944 $\times 10^{-3}$	$C_9$ -1.0105 $\times 10^{-4}$
$C_{10}$ 1.3271 $\times 10^{-4}$	$C_{12}$ 8.3881 $\times 10^{-7}$	$C_{14}$ -5.1811 $\times 10^{-7}$
$C_{15}$ -4.1104 $\times 10^{-7}$	$C_{17}$ -2.0403 $\times 10^{-10}$	$C_{19}$ -6.0184 $\times 10^{-4}$
$C_{21}$ -4.1181 $\times 10^{-4}$	$C_{23}$ 4.4143 $\times 10^{-10}$	$C_{25}$ 3.8170 $\times 10^{-10}$
$C_{27}$ 8.4970 $\times 10^{-11}$	$C_{29}$ -2.8001 $\times 10^{-10}$	$C_{30}$ 1.3164 $\times 10^{-12}$
$C_{31}$ -1.7177 $\times 10^{-10}$	$C_{33}$ 3.3220 $\times 10^{-11}$	$C_{34}$ 1.4101 $\times 10^{-12}$

[0129]

## 実施例13

面番号	曲率半径	間隔	屈折率 (偏心率)	アッペ数 (傾き角)
1	$\infty$ (面)		1.5113	44.15
2	自由曲面① (1ST SF)		Y 0.000 Z 35.517	$\theta$ 24.73°
3	自由曲面② (2ND SF)		Y 5.402 Z 70.723	$\theta$ -4.11°
4	自由曲面③ (3RD SF)		Y 11.138 Z 31.783	$\theta$ -25.13°
5	$\infty$		Y 23.913 Z 31.441	$\theta$ -11.11°

自由曲面④

$C_1$ -3.7101 $\times 10^{-3}$	$C_7$ -4.1031 $\times 10^{-3}$	$C_9$ 4.2881 $\times 10^{-4}$
$C_{10}$ -8.4314 $\times 10^{-4}$	$C_{12}$ -8.1477 $\times 10^{-4}$	$C_{14}$ 1.1844 $\times 10^{-4}$
$C_{15}$ 2.8108 $\times 10^{-7}$	$C_{17}$ 8.8833 $\times 10^{-4}$	$C_{19}$ 3.2284 $\times 10^{-4}$
$C_{21}$ 1.2745 $\times 10^{-4}$		
$C_1$ 1.5113 $\times 10^{-3}$	$C_7$ 1.5801 $\times 10^{-3}$	$C_9$ 3.8223 $\times 10^{-4}$

[0130]

17	$C_{10} = -5.954 \times 10^{-4}$	$C_{11} = -5.810 \times 10^{-4}$	$C_{12} = -4.351 \times 10^{-4}$
	$C_{13} = -2.215 \times 10^{-4}$	$C_{14} = 1.1840 \times 10^{-4}$	$C_{15} = 2.0760 \times 10^{-4}$
	$C_{16} = 1.011 \times 10^{-4}$		

実施例 14

面番号	曲率半径	間隔	屈折率 (傾心量)	アッペ数 (傾心角)
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1	$\infty$ (傾)			
2	自由曲面① (1ST SF)		1.5113	14.15°
			Y -10.123	$\theta$ 10.33°
			Z 43.469	
3	自由曲面② (2ND SF)		1.5113	14.15°
	(32FL)		Y 1.103	$\theta$ -10.31°
			Z -15.000	
4	自由曲面③ (1ST SF)		Y -10.123	$\theta$ 10.33°
			Z 43.469	
5	$\infty$ (画像表示面)		Y 17.408	$\theta$ -13.11°
			Z 30.444	

自由曲面①

$C_1$	$1.0401 \times 10^{-3}$	$C_7$	$1.6377 \times 10^{-4}$	$C_4$	$1.8317 \times 10^{-4}$
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$C_6$	$1.0451 \times 10^{-4}$	$C_{11}$	$-1.4215 \times 10^{-4}$	$C_{15}$	$1.1312 \times 10^{-4}$
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$C_{16}$	$4.0501 \times 10^{-4}$	$C_{17}$	$3.2411 \times 10^{-4}$	$C_{18}$	$1.1071 \times 10^{-3}$
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$C_{19}$	$1.5355 \times 10^{-3}$				
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自由曲面②

$C_1$	$-1.5718 \times 10^{-3}$	$C_7$	$-3.0703 \times 10^{-3}$	$C_4$	$-3.3014 \times 10^{-4}$
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$C_{10}$	$-3.3103 \times 10^{-4}$	$C_{13}$	$1.3430 \times 10^{-4}$	$C_{14}$	$4.3417 \times 10^{-4}$
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$C_{16}$	$3.4181 \times 10^{-4}$	$C_{17}$	$-1.8713 \times 10^{-4}$	$C_{18}$	$4.0815 \times 10^{-4}$
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$C_{19}$	$5.4111 \times 10^{-4}$				
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[0131]

実施例 17

面番号	曲率半径	間隔	屈折率 (傾心量)	アッペ数 (傾心角)
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1	$\infty$ (傾)			
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2	自由曲面① (1ST SF)		1.5000	55.55°
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			Y 18.958	$\theta$ 7.41°
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			Z 30.730	
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3	自由曲面② (2ND SF)		1.5000	55.55°
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	(32FL)		Y 9.165	$\theta$ -13.84°
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			Z 46.107	
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4	自由曲面③ (1ST SF)		1.5000	55.55°
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	(32FL)		Y 18.958	$\theta$ 7.41°
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			Z 30.730	
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5	自由曲面④ (2ND SF)		1.5000	55.55°
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	(32FL)		Y 9.165	$\theta$ -13.84°
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			Z 46.107	
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6	自由曲面⑤ (1TH SF)		1.5000	55.55°
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			Y 34.128	$\theta$ -31.50°
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			Z 30.758	
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7	$\infty$ (画像表示面)		Y 47.350	$\theta$ -34.31°
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			Z 35.813	
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(11)

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$C_1$	$-4.9443 \times 10^{-3}$	$C_7$	$-3.4412 \times 10^{-3}$	$C_4$	$1.4477 \times 10^{-4}$
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$C_{10}$	$1.7114 \times 10^{-4}$	$C_{13}$	$1.0430 \times 10^{-4}$	$C_{14}$	$-2.3541 \times 10^{-4}$
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$C_{16}$	$4.5743 \times 10^{-4}$	$C_{17}$	$1.5811 \times 10^{-4}$	$C_{18}$	$4.7167 \times 10^{-4}$
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$C_{19}$	$-1.3331 \times 10^{-3}$	$C_{22}$	$-1.3103 \times 10^{-10}$	$C_{23}$	$-7.7572 \times 10^{-10}$
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$C_{24}$	$7.0733 \times 10^{-10}$	$C_{25}$	$5.3774 \times 10^{-11}$	$C_{26}$	$4.7718 \times 10^{-11}$
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$C_{27}$	$1.3111 \times 10^{-11}$	$C_{28}$	$7.4217 \times 10^{-11}$	$C_{29}$	$-1.3440 \times 10^{-10}$
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$C_1$	$-5.1343 \times 10^{-3}$	$C_7$	$-5.4503 \times 10^{-3}$	$C_4$	$3.4016 \times 10^{-4}$
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$C_{10}$	$7.3133 \times 10^{-4}$	$C_{13}$	$-4.1470 \times 10^{-7}$	$C_{14}$	$1.0233 \times 10^{-4}$
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$C_{16}$	$1.4471 \times 10^{-4}$	$C_{17}$	$2.3015 \times 10^{-4}$	$C_{18}$	$3.3134 \times 10^{-4}$
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$C_{19}$	$-1.4453 \times 10^{-4}$	$C_{22}$	$-1.3355 \times 10^{-10}$	$C_{23}$	$-4.3215 \times 10^{-10}$
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$C_{24}$	$-3.3070 \times 10^{-10}$	$C_{25}$	$4.1305 \times 10^{-11}$	$C_{26}$	
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$C_1$	$7.7118 \times 10^{-3}$	$C_7$	$1.7545 \times 10^{-3}$	$C_4$	$-1.1010 \times 10^{-4}$
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$C_{10}$	$1.4312 \times 10^{-4}$	$C_{13}$	$-3.1311 \times 10^{-4}$	$C_{14}$	$-7.3311 \times 10^{-4}$
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$C_{16}$	$-1.4173 \times 10^{-4}$				
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(1) $\theta_{1,2} = 40.48^\circ$					
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\*ことは言うまでもない。

[0132] 以上の実施例では、前記定義式 (a)、

(b)、(c) の非球面、アサセリフレンズ面、自由曲

面で構成したため、次の定義式 (d) のように定義した Z

ernike 多項式で表される面形状、次の定義式

(e) のように定義した X 方向に対称な自由曲面での設

計も可能である。つまり、あらゆる定義の曲面が使え

る。

X = R × cos (A)

Y = R × sin (A)

Z = D<sub>1</sub>+ D<sub>2</sub> × R cos (A) + D<sub>3</sub> × R sin (A)+ D<sub>4</sub> × R<sup>2</sup> cos (A) + D<sub>5</sub> × (3R<sup>2</sup> - 2R) cos (A)+ D<sub>10</sub> × (3R<sup>2</sup> - 2R) sin (A) + D<sub>11</sub> × R<sup>2</sup> sin (A)+ D<sub>12</sub> × R<sup>2</sup> cos (A) + D<sub>13</sub> × (4R<sup>4</sup> - 3R<sup>2</sup>) cos (A)+ D<sub>14</sub> × (6R<sup>4</sup> - 6R<sup>2</sup> + 1) + D<sub>15</sub> × (4R<sup>4</sup> - 3R<sup>2</sup>) sin (A)+ D<sub>16</sub> × R<sup>4</sup> sin (A) + D<sub>17</sub> × R<sup>4</sup> cos (A)+ D<sub>18</sub> × (5R<sup>4</sup> - 4R<sup>2</sup>) cos (A)+ D<sub>19</sub> × (10R<sup>4</sup> - 12R<sup>2</sup> + 3R) cos (A)+ D<sub>20</sub> × (10R<sup>4</sup> - 12R<sup>2</sup> + 3R) sin (A)+ D<sub>21</sub> × (5R<sup>4</sup> - 4R<sup>2</sup>) sin (A) + D<sub>22</sub> × R<sup>4</sup> sin (A)+ D<sub>23</sub> × R<sup>4</sup> cos (A) + D<sub>24</sub> × (6R<sup>4</sup> - 5R<sup>2</sup>) cos (A)+ D<sub>25</sub> × (15R<sup>4</sup> - 20R<sup>2</sup> + 6R<sup>2</sup>) cos (A)+ D<sub>26</sub> × (20R<sup>4</sup> - 30R<sup>2</sup> + 12R<sup>2</sup> - 1)+ D<sub>27</sub> × (15R<sup>4</sup> - 20R<sup>2</sup> + 6R<sup>2</sup>) sin (A)+ D<sub>28</sub> × (6R<sup>4</sup> - 5R<sup>2</sup>) sin (A) + D<sub>29</sub> × R<sup>4</sup> sin (A) . . . . . (d)

なお、上記において X 方向に対称な面として表した。た

だし、D<sub>m</sub> (m は 2 以上の整数) は係数である。 ※ 式に

対称して次のように定義できる。

Z = C<sub>1</sub>+ C<sub>2</sub> × Y + C<sub>3</sub> × |X|+ C<sub>4</sub> × Y<sup>2</sup> + C<sub>5</sub> × Y |X| + C<sub>6</sub> × X<sup>2</sup>+ C<sub>7</sub> × Y<sup>2</sup> + C<sub>8</sub> × Y<sup>2</sup> |X| + C<sub>9</sub> × YX<sup>2</sup> + C<sub>10</sub> × |X<sup>3</sup>|





55

【0155】(16) 上記(12)から(14)の何れか1項において、前記カメラ観察作用は前記第1面と前記第3面の少なくとも一部の領域における合成のバーが接ゼロとなるように形成されていることを特徴とする像観察装置。

【0156】(16) 上記(12)から(15)の何れか1項において、前記第1面と前記第3面とが曲面に形成されていることを特徴とする像観察装置。

【0157】(17) 上記(12)から(16)の何れか1項において、前記第1面と前記第3面とが曲面に形成されていることを特徴とする像観察装置。

−0.5 ≤  $\phi$  ≤ 0.5 (1/mm)

... (3)

を測たすことを特徴とする像観察装置。  
【0160】(20) 上記(12)から(19)の何れか1項において、前記プリズム部材は、前記像形成手段によって形成された像の観察時及び前記カメラ観察作用によって形成された像の観察時及び前記カメラ観察作用によって形成された像の観察時においても同じ位置に固定されているように形成されていることを特徴とする像観察装置。

【0161】(21) 上記(20)において、前記第1面と前記第3面を通して、部分領域別に前記像形成手段からの像と外界像を観察可能であることを特徴とする像観察装置。

【0162】(22) 上記(12)から(19)の何れか1項において、前記プリズム部材は、前記像形成手段によって形成された像の観察と前記外界像の観察とを切り替える切替手段を有し、前記切替手段は、前記プリズム部材を移動させる機能を有するように形成されていることを特徴とする像観察装置。

【0163】(23) 上記(22)において、前記切替手段は、前記像形成手段によって形成された像を観察する際の前記プリズム部材から観察者眼球に至る光路が、前記外界像を観察する際の前記プリズム部材から観察者眼球に至る光路と略一致するように前記プリズム部材を移動させることを特徴とする像観察装置。

【0164】(24) 上記(22)又は(23)において、前記切替手段は、前記プリズム部材を軸上主光線の光路を含む面においた方向に移動可能となるように移動させる構成を有することを特徴とする像観察装置。

【0166】(26) 上記(22)又は(23)において、前記切替手段は、前記プリズム部材を回転可能となるように移動させる構成を有することを特徴とする像観察装置。

【0167】(27) 像形成手段と、前記像形成手段によって形成された像を観察面状に導く作用を持った接眼光学系とを有する像観察装置において、前記接眼光学系が少なくともプリズム部材を含み、前記プリズム部材は、その面構成の中、透過又は反射の光学作用を持った光学作用面が少なくとも4つ設けられ、かつ、その4つ

51

\*れか1項において、前記第1面と前記第3面とが球面に形成されていることを特徴とする像観察装置。

【0158】(18) 上記(12)から(14)の何れか1項において、前記第1面と前記第3面とが平面にて形成されていることを特徴とする像観察装置。

【0159】(19) 上記(12)から(18)の何れか1項において、前記第1面と前記第3面との任意の場所における合成のバーを $\phi$ とする場合、

... (3)

の光学作用面で屈折率(n)が1よりも大きい(n>1)単体媒質で埋めて構成され、前記4つの光学作用面は、透過作用と反射作用とを有し観察者眼球側に配置された第1面と、前記第1面に対して前記媒質を挟んで対向配置されかつ観察者視線に対して少なくとも偏心あるいは傾いて配置された反射作用を有する第2面と、前記第1面に対して前記媒質を挟んで対向配置されかつ前記第2面に対して前記媒質を挟んで対向配置された反射作用を有する第3面と、一方の端部を前記第1面に傾斜接せしめ他方の端部を前記第3面に傾斜接せしめるように配置した第4面とを有し、少なくとも前記第2面又は前記第3面が全反射作用を有するように前記プリズム部材が構成されていると共に、前記全反射作用を有する前記第2面又は前記第3面の全反射作用を生じる領域(部分)に観察者の視線を抽出する作用を持った視線抽出手段を配置したことを特徴とする像観察装置。

【0168】(28) 上記(27)において、前記第1面が全反射作用を有するように前記プリズム部材が構成されていることを特徴とする像観察装置。  
【0169】(29) 上記(28)において、前記視線抽出手段は、前記第2面又は前記第3面の全反射領域を通して観察者の視線を抽出する位置に配置されていることを特徴とする像観察装置。

【0170】(30) 上記(27)から(29)の何れか1項において、前記観察者眼球を照明する照明手段を有することを特徴とする像観察装置。  
【0171】(31) 上記(30)において、前記照明手段は赤外光を用いるものであることを特徴とする像観察装置。

【0172】(32) 上記(31)において、前記接眼光学系と前記像形成手段と前記視線抽出手段とを観察者眼面に保持する作用を持った保持部材を備えていることを特徴とする両面装型型面像表示装置。

【0173】(33) 上記(10)、(14)から(26)、(32)の何れか1項において、前記像形成手段と前記接眼光学系を観察者眼面に対して位置決めする位置決め手段を有することを特徴とする像観察装置。

【0174】(34) 上記(10)、(14)から(26)、(32)、(33)の何れか1項において、前記像観察装置の少なくとも2組を一定の間隔で支持す

57

る支持手段を有することを特徴とする像観察装置。

【0175】(35) 上記(1)～(10)及び(27)～(34)の何れか1項において、前記第2面及び前記第3面とが、光学作用的には別々の面として作用し、かつ、構成的には1つの面にて形成されていることを特徴とするプリズム光学素子又はプリズム部材。

【0176】(36) 上記(35)において、前記第2面と前記第3面とを構成する1つの面は、前記第4面に近い領域が第3面として作用し、前記第4面から遠い領域が第2面として作用するように構成されていることを特徴とするプリズム光学素子又はプリズム部材。

【0177】(37) 上記(36)において、前記第2面と前記第3面とを構成する1つの面は、中央領域が第2面と第3面との両方の作用を兼用するように構成されていることを特徴とするプリズム光学素子又はプリズム部材。

【0178】  
【発明のめあて】以上の説明から明らかなように、本発明によると、非常に薄型で小型の接眼光学系でありながら、不要光が少なく、広い観察面内においても明瞭な観察像を有する像観察装置としての画像表示装置を提供することができ。

【図面の簡単な説明】  
【図1】本発明の実施例1の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図2】本発明の実施例2の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

【図3】本発明の実施例3の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図4】本発明の実施例4の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図5】変形例(a)と対比しながら本発明(b)の実施例5の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

【図6】本発明の実施例6の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図7】本発明の実施例7の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図8】本発明の実施例8の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図9】本発明の実施例9の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図10】本発明の実施例10の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

【図11】本発明の実施例11の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図12】本発明の実施例12の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

(10)

特開平10-307263

57

る。

【図13】本発明の実施例13の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図14】本発明の実施例14の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

【図15】本発明の実施例15の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図16】本発明の実施例16の接眼光学系を用いた頭部装型型面像表示装置の断面図である。

【図17】本発明の実施例17の接眼光学系を用いた頭部装型型面像表示装置の断面図である。  
【図18】実施例17のような接眼光学系に視線抽出手段を設けた場合の断面図である。  
【図19】実施例17のような接眼光学系を電子像観察位置から外界像観察位置へ変換する場合の移動方向と機構を示す図である。

【図20】本発明において全反射面により不要光を除去する作用を説明するための図である。  
【図21】本発明の画像表示装置を片眼装型用構成にした場合の様子を示す図である。  
【図22】本発明の画像表示装置を両眼装型用構成にした場合の様子を示す図である。

【図23】本発明による光学系を結像光学系として利用した場合の構成図である。  
【図24】本発明による光学系を結像光学系として利用した場合の光学系の構成図である。

【符号の説明】  
1...射出位置(観察者位置)  
2...観察者視線(軸上主光線)  
3...接眼光学系の第1面  
4...接眼光学系の第2面  
5...接眼光学系の第3面  
6...接眼光学系の第4面  
7...画像表示素子  
8...フレネルレンズ  
9...視線抽出光学系  
10...視線抽出器  
11...照明手段  
12...接眼光学系(中心プリズム)  
13、14...第2光学素子  
15...観察者眼球  
16...光学フイルター  
17...リニアエーダー  
18...光学素子に設けられた突出部  
19...外装部に設けられたガイド(レール)

51

51

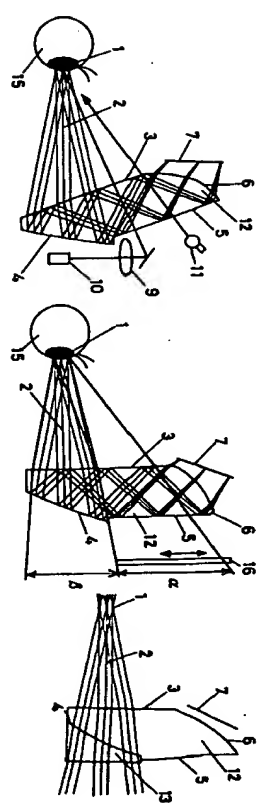
- 31...表示装置本体部  
 32...前フィルム  
 33...後フィルム  
 34...頭面フィルム  
 35...リヤフィルム  
 36...リヤカバー  
 39...スピーカ  
 40...ビデオ再生装置  
 40a...スイッチ、ボリュウム調整部  
 41...ケーブル

【図1】

【図2】

【図3】

- NC...コーティング穴  
 Ob...撮影光学系  
 F1...ファインダー光学系  
 Ca...コンパクトカメラ  
 GF...前面レンズ群  
 D...明るさ絞り  
 DS...撮影光学系 (本発明)  
 Lt...対物光学系  
 P...ポロプリズム  
 Oc...接眼レンズ



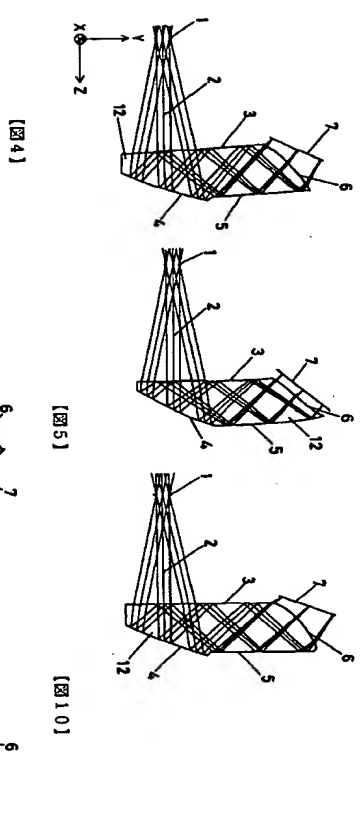
【図6】

【図7】

【図15】

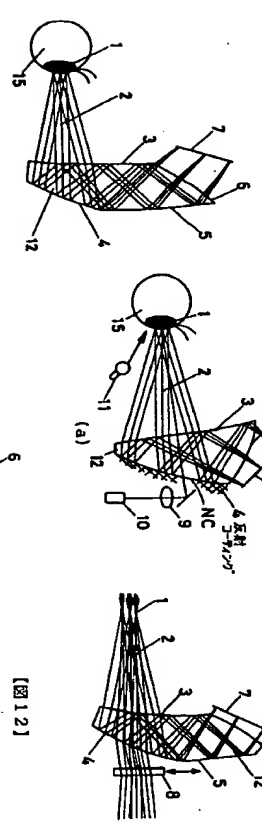
【図8】

【図9】



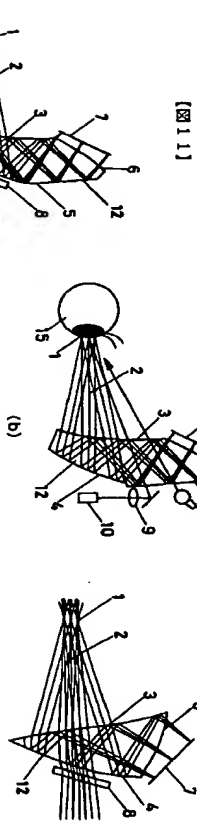
【図5】

【図10】



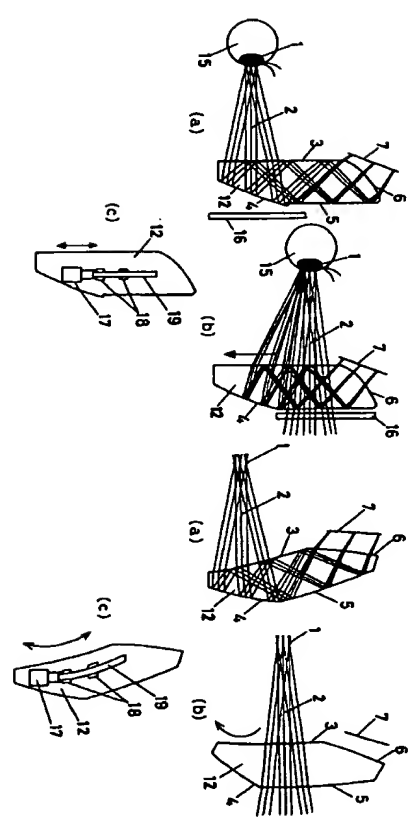
【図4】

【図11】



【図11】

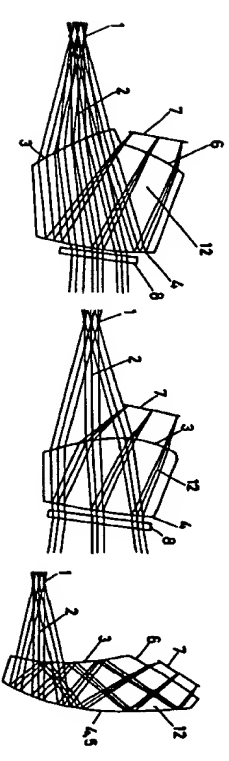
【図12】



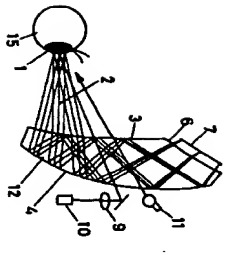
【図13】

【図14】

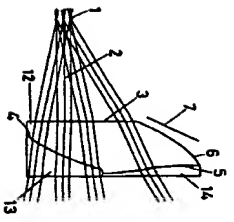
【図16】



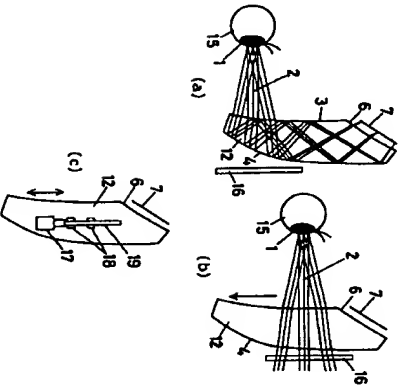
【図17】



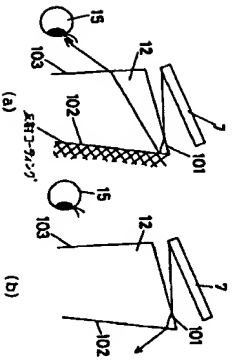
【図19】



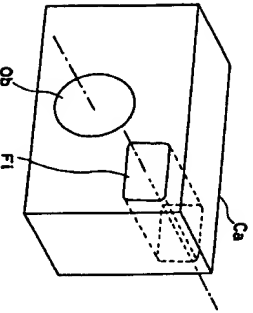
【図18】



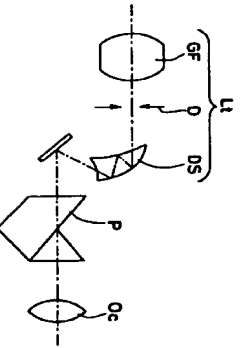
【図20】



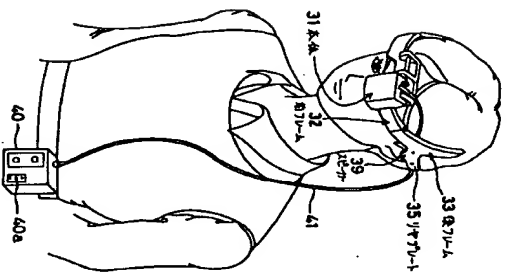
【図23】



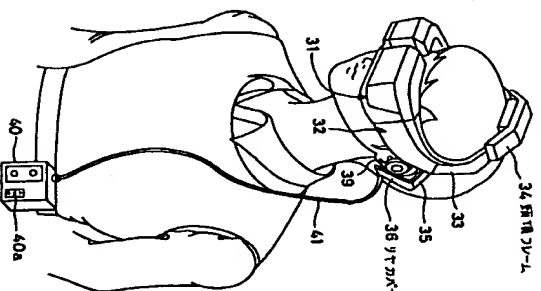
【図24】



【図21】



【図22】



JAPANESE LAID-OPEN PATENT APPLICATION

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(22)	Date of Filing	May 7, 1997
(71)	Assignee	Olympus Optical Co., Ltd.
(72)	Inventors	Takahashi, Junko Takahashi, Koich
(73)	Title of the Invention	Prism Optical Element and Image Viewing Apparatus

[Claims]

[Claim 1] A prism optical element comprising a plurality of surfaces between which a medium having a refractive index (n) higher than 1 ( $n > 1$ ) is sandwiched,

characterized in that the prism optical element has: a first surface having both a transmission property of making a light ray enter the prism optical element or making a light ray exit from the prism optical element, and an internal reflection property in the prism optical element; a second surface disposed so as to be opposed to the first surface with the medium in between, and having an internal reflection property in the prism optical element; a third surface disposed in a position substantially in the vicinity of the second surface so as to be opposed to the first surface with the medium in between, and having an internal reflection property in the prism optical element; and a fourth surface having a transmission property of making the light ray exit from the prism optical element when the first surface has the property of making the light ray enter the prism optical element, and making the light ray enter the prism optical element when the first surface has the property of making the light ray exit from the prism optical element, and when the refractive index, to the d-line, of the medium is  $n_d$  and the angle of internal reflection of a given light ray at the third surface is  $\theta_o$ , the following expression (1) is satisfied:

$$\sin^{-1}(1/n_d) \leq \theta_o \leq 60^\circ \quad \dots (1)$$

[Claim 2] An image viewing apparatus having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, characterized in that the eyepiece optical system has a prism member having a surface structure provided with at least three surfaces among which a single medium having a refractive index (n) higher than 1 ( $n > 1$ ) is filled, the prism member internally reflects at least three times a light ray emanating from the image forming means, at least two of the at least three internal reflections is total reflection, at least one of the at least two total reflections is performed by a surface disposed on the

viewer side of the single medium of the prism member, the surface is a curved surface that corrects an aberration caused by the internal reflection by the prism member, and

in order that the outside world can be viewed through at least two of the at least three surfaces of the prism member, the at least two surfaces are disposed opposed to each other so as to decrease distortion caused when the outside world is viewed with the single medium sandwiched therebetween.

[Claim 3] An image viewing apparatus having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball,

characterized in that the eyepiece optical system includes at least a prism member, the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces is filled with a single medium having a refractive index (n) higher than 1 ( $n > 1$ ),

the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface,

the prism member is structured so that at least the third surface has a total reflection property, and the first surface, the single medium and the third surface are structured so as to have an outside world viewing property that enables the outside world to be viewed through the first surface, the single medium and the third surface.

[Claim 4] An image viewing apparatus having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, characterized in that the eyepiece optical system includes at least a prism member,

the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces is filled with a single medium having a refractive index (n) higher than 1 ( $n > 1$ ),

the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface,

the prism member is structured so that at least the second surface or the third surface has a total reflection property, and line of sight detecting means for detecting the viewer's line of sight is disposed in the vicinity of an area where total reflection by the second surface or the third surface having the total reflection property is caused.

#### [Detailed Description of the Invention]

[Technical Field of the Invention] The present invention relates to a prism optical element and an image viewing apparatus, and more particularly, to a head - or face - mounted image display apparatus capable of being held on the viewer's head or face.

[Prior Art] Examples of a heretofore known head - or face - mounted image display apparatus include



one disclosed in Japanese Laid-open Patent Application No. H3-101709. In this image display apparatus, the image displayed on the image display device is transmitted as an aerial image by a relay optical system comprising positive lens elements, the aerial image is enlarged by an eyepiece optical system comprising a concave reflecting mirror, and the enlarged image is projected within the viewer's eye ball.

Examples of another type of conventional image display apparatus is one disclosed in United States Patent No. 4,669,810. In this apparatus, an intermediate image of the image on a CRT is formed through a relay optical system, and the intermediate image is projected onto the viewer's eye by a combiner having a reflection holographic element and a hologram surface.

Examples of yet another type of conventional image display apparatus include one disclosed in United States Patent No. 4,026,641. In this apparatus, the image on the image display device is transmitted to a curved object surface by a transfer element, and the object surface is projected in the air by a toric reflecting surface.

Examples of still another type of conventional image display device include one disclosed in United States Reissued Patent No. 27,356. This apparatus is an eyepiece optical system that projects the object surface onto the exit pupil by a semitransparent concave mirror and a semitransparent plane mirror.

Ones disclosed in the following are also known: United States Patent No. 4,322,135; United States Patent No. 4,969,724; European Patent No. 0,583,116A2; and Japanese Laid-open Patent Application No. H7-333551.

[Problem to be Solved by the Invention] However, in the image display apparatuses of the type in which the image on the image display device is relayed like the ones disclosed in Japanese Laid-open Patent Application No. H3-101709 and United States Patent No. 4,669,810, since it is necessary to use several lens elements as the relay optical system in addition to the eyepiece optical system irrespective of the form of the eyepiece optical system, the optical path length is large, so that

the optical system is large in size and heavy in weight.

A head-mounted image display apparatus is worn on the human body, particularly on the head. Therefore, when the amount of protrusion of the apparatus from the face is large, the distance from the point at which the apparatus is supported on the head to the center of gravity of the apparatus is long, which results in poor balance when the apparatus is worn. In addition, there is a fear that the apparatus bumps against an object when the viewer wearing the apparatus moves or turns. That is, it is important for head-mounted image display apparatuses to be compact and lightweight. A great factor that decides the size and weight of the apparatus is the optical system structure.

However, when only a normal magnifier is used as the eyepiece optical system, an extremely large amount of aberration is generated and there is no means for correcting it. Although spherical aberration can be corrected to some extent by making the concave surface of the magnifier aspherical, since aberrations such as coma aberration and curvature of field remain, the apparatus cannot be practical when the viewing angle is large. When only a concave mirror is used as the eyepiece optical system, means such that the generated curvature of field is corrected by a conduction element (fiber plate) having a surface curved in accordance with the curvature of field must be used as well as normal optical elements (lens elements and mirrors).

In the type in which the image on the image display device is projected onto the viewer's eye ball by use of a toric reflecting surface like the one disclosed in United States Patent No. 4,026,641, since curvature of field caused by the decentered toric reflecting surface is corrected by curving the object surface itself, it is difficult to use a so-called flat display such as an LCD (liquid crystal display device) as the image display device.

In the coaxial eyepiece optical system that projects the object surface onto the viewer's pupil by use of a semitransparent concave mirror and a semitransparent plane mirror like the one disclosed in United States Reissued Patent No. 27,356, since two semitransparent surfaces are used,

the image brightness decreases to as low as 1/16 even in theoretical value. In addition, since curvature of field caused by the semitransparent concave mirror is corrected by curving the object surface itself, it is difficult to use a flat display such as an LCD (liquid crystal display device) as the image display device like the conventional example described above.

The present invention is made in view of the above-mentioned prior art problem, and an object thereof is to provide a very-small-size image viewing apparatus that provides a clear viewing image with few distortions and few aberrations even at a wide angle of view, and a prism optical element used for the image viewing apparatus.

[Means for Solving the Problem] In a prism optical element of the present invention achieving the above-mentioned object and comprising a plurality of surfaces between which a medium having a refractive index (n) higher than 1 ( $n > 1$ ) is sandwiched, the prism optical element has: a first surface having both a transmission property of making a light ray enter the prism optical element or making a light ray exit from the prism optical element, and an internal reflection property in the prism optical element; a second surface disposed so as to be opposed to the first surface with the medium in between, and having an internal reflection property in the prism optical element; a third surface disposed in a position substantially in the vicinity of the second surface so as to be opposed to the first surface with the medium in between, and having an internal reflection property in the prism optical element; and a fourth surface having a transmission property of making the light ray exit from the prism optical element when the first surface has the property of making the light ray enter the prism optical element, and making the light ray enter the prism optical element when the first surface has the property of making the light ray exit from the prism optical element, and when the refractive index, to the d-line, of the medium is  $n_d$  and the angle of internal reflection of a given light ray at the third surface is  $\theta_o$ , the following expression (1) is satisfied:

$$\sin^{-1}(1/n_d) \leq \theta_o \leq 60^\circ \quad \dots (1)$$

In the present invention, the structure of the second surface and the third surface is not

limited to the one in which separately designed surfaces are disposed adjacent to each other, but includes a structure using one surface one partial area of which acts as the second surface and another partial area of which acts as the third surface. In that case, needless to say, an overlapping area that acts both the second surface and the third surface may be present because a ray bundle has a width.

In an image viewing apparatus according to the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system has a prism member having a surface structure provided with at least three surfaces among which a single medium having a refractive index (n) higher than 1 ( $n > 1$ ) is filled, the prism member internally reflects at least three times a light ray emanating from the image forming means, at least two of the at least three internal reflections is total reflection, at least one of the at least two total reflections is performed by a surface disposed on the viewer side of the single medium of the prism member, the surface is a curved surface that corrects an aberration caused by the internal reflection by the prism member, and in order that the outside world can be viewed through at least two of the at least three surfaces of the prism member, the at least two surfaces are disposed opposed to each other so as to decrease distortion caused when the outside world is viewed with the single medium sandwiched therebetween.

In another image viewing apparatus of the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system includes at least a prism member, the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces and a surface other than the four surfaces is filled with a single medium having a refractive index (n) higher than 1 ( $n > 1$ ), the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a

reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface, the prism member is structured so that at least the third surface has a total reflection property, and the first surface, the single medium and the third surface are structured so as to have an outside world viewing property that enables the outside world to be viewed through the first surface, the single medium and the third surface.

In still another image viewing apparatus of the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system includes at least a prism member, the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces is filled with a single medium having a refractive index ( $n$ ) higher than 1 ( $n > 1$ ), the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface, the prism member is structured so that at least the second surface or the third surface has a total reflection property, and line of sight detecting means for detecting the viewer's line of sight is disposed in the vicinity of an area where total reflection by the second surface or the third surface

having the total reflection property is caused.

In the present invention, the structure of the second surface and the third surface is not limited to the one in which separately designed surfaces are disposed adjacent to each other, but includes a structure using one surface one partial area of which acts as the second surface and another partial area of which acts as the third surface. In that case, needless to say, an overlapping area that acts both the second surface and the third surface may be present because a ray bundle has a width.

Hereinafter, the structures, actions and effects of the prism optical element, the image viewing apparatus and the image display apparatus of the present invention will be described.

Particularly in the description of the image viewing apparatus and the image display apparatus, for convenience in the optical system design, description will be given based on backward ray tracing in which a light ray is traced from the position of the viewer's pupil to the image display device unless otherwise specified.

In this image viewing apparatus, the effect of bending the optical path is great by a light ray from the image display device (image forming means) being internally reflected three times in the eyepiece optical system, so that a very thin eyepiece optical system is realized. Further, by two of the three internal reflections being total reflection, the area covered with reflective coating is extremely small, and thus, the present invention succeeds in realizing a compact, lightweight and low-cost eyepiece optical system. Further, by two of the three internal reflections being total reflection, generation of a ghost image due to generation of unnecessary light, or decrease in contrast due to flare can be reduced. Normally, in an optical system having internal reflection and filled with an optical medium of a refractive index higher than 1, influences of light exiting from the image display device at a large angle and unnecessary light due to reflection not on the normal light ray path are a problem. According to the present invention, since the area covered with reflective coating is small because of the use of two totally reflecting surfaces, unnecessary light other than the

normal luminous flux that reaches the pupil from the image display device passes through the two internally reflecting surfaces, so that the unnecessary light that reaches the viewer's pupil is significantly reduced.

This action will be detailed with reference to FIG. 20. FIG. 20 is an enlarged view of a portion, on which light from an image display device 7 is incident, of a decentered prism 12 in which a space formed by three surfaces 101, 102 and 103 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1. Reference numeral 15 represents the viewer's eye ball. Reference numeral 101 represents an incident surface. Reference numeral 102 represents an outside world side reflecting or totally reflecting surface. Reference numeral 103 represents a viewer side refracting or reflecting surface. (a) of FIG. 20 shows a case where the reflecting surface 102 is covered with reflective coating. (b) of FIG. 20 shows a case where the reflecting surface 102 is a totally reflecting surface and is not covered with reflective coating. In the case of (a) of FIG. 20, light exiting from the left side of the image display device 7 at a large angle is incident on the incident surface 101 of the decentered prism 12 to be refracted, is reflected at the reflecting surface 102 covered with reflective coating, and passes through the refracting surface 103 to be incident on the viewer's eye ball 15. Consequently, the viewer sees an unnecessary electronic image in an upper part of the viewer's field of view in addition to the normal image on the image display device 7 (hereinafter, referred to as electronic image) or flare is caused in an upper part.

In the case of (b) of FIG. 20, light exiting from the left side of the image display device 7 at a large angle is incident on the incident surface 101 of the decentered prism 12 to be refracted, and passes through the reflecting surface 102 not covered with reflective coating because the light is incident thereon at an angle not more than a critical angle. Consequently, the light is transmitted toward the side opposite to the viewer and is not incident on the viewer's eye ball 15. That is, a ghost image or flare is not caused.

The above-described action can similarly be caused at a totally reflecting surface in cases other than this example. This can be achieved by setting the luminous flux of a light ray path for viewing the normal electronic image, so as to have an incident angle not less than a critical angle, and setting other luminous fluxes with exit angles that can cause a ghost or flare, so as to be at an angle not more than the critical angle at the totally reflecting surface. By providing two totally reflecting surfaces, the above-described effect is easily obtained, so that a clear viewing image with no ghost image and little reduction in contrast due to flare can be provided to the viewer.

First, in the prism optical element of the present invention, assuming that it is used as an eyepiece optical system (viewing optical system) of an image viewing apparatus or an image display apparatus, since it comprises a prism member that causes internal reflection at least three times and the prism member is filled with a medium having a refractive index higher than 1, in addition to the effect that the eyepiece optical system can significantly be reduced in thickness by the above-described effect of bending the optical path, the effect of a aberration correction because of the structure in which internal reflection is caused at least three times is great, so that a clear viewing image can be provided in the entire area of the screen. This will be detailed below.

The principal optical power of the prism optical element is provided by the second surface which is a reflecting surface. In this case, since the optical system can be structured with a large radius of curvature compared to a refractive system having the same optical power, aberration generation can be reduced. Since the outside world side reflecting surface is divided into two different surfaces (the second surface and the third surface), the reflected light can be set in a desired direction without depending on the curvature of each surface. Therefore, the optical system can be provided with a shape conforming to the shape of the viewer's face, and the image display device can be disposed with its back facing the viewer side. Particularly, in the case of an image display device requiring a backlight such as an LCD, since the backlight and the electric system are disposed on the viewer side, the image display apparatus does not protrude forward, so that the overall

protrusion of the image display apparatus can be minimized.

Generally, when a concave mirror is disposed so as to be decentered or inclined with respect to the optical axis, aberrations due to decentring that are not caused in coaxial systems are caused. In the prism optical element of the present invention, when it is used for an image viewing apparatus or an image display apparatus, since the second surface is decentered or inclined with respect to the viewer's axis of sighting, aberrations due to decentring are caused. Particularly, since the axial optical power in a direction along within a plane including the optical path of the axial principal ray (tangential direction) and that in a direction including the axis of sighting and vertical to a plane including the optical path of the axial principal ray (sagittal direction) are different, astigmatism and coma aberration are caused. To correct these decentring aberrations, by at least one of the at least four surfaces constituting the prism optical element being a surface where the optical power in the tangential direction and that in the sagittal direction are different, that is, a rotationally asymmetric surface, the decentring aberrations caused on the second surface can be corrected.

Further, it is effective for the prism optical element to comprise surfaces including only one symmetric surface. When the image display device is disposed on the viewer's axis of sighting (axial principal ray), by at least one of the surfaces constituting the eyepiece optical system being a surface having a symmetric surface in the sagittal direction, a horizontally symmetric viewing image can be projected onto the viewer's eye ball. On the other hand, by providing no symmetric surface in the tangential direction of the surface, the degree of freedom in the tangential direction increases, so that the decentring aberrations caused within the plane including the optical path of the axial principal ray can more excellently be corrected.

When the eyepiece optical system comprises at least four surfaces, the reflection at the first surface can be total reflection. By the first surface disposed immediately before the viewer's pupil being a totally reflecting surface, the area where a light ray exits from the eyepiece optical

system and the internal reflection area can be overlapped with each other. That is, one surface can be provided with two properties, which enables size reduction of the eyepiece optical system.

Moreover, since the above-mentioned effect of reducing ghost or flare by a totally reflecting surface is also obtained on the first surface, a clearer viewing image can be provided.

Further, since reflective coating is provided only on the second surface, manufacturability improves, so that a more inexpensive image display apparatus can be realized.

Moreover, in the prism optical element, when the refractive index, to the d-line, of the medium is  $n_d$  and the angle of internal reflection of a given light ray at the third surface is  $\theta_a$ , it is desirable to satisfy

$$\sin^{-1}(1/n_d) \leq \theta_a \leq 60^\circ \quad \dots (1)$$

It is important to satisfy the expression (1). By  $\theta_a$  being not less than the lower limit  $\sin^{-1}(1/n_d)$ , the angle of internal reflection at the third surface is not less than the critical angle, so that the given light ray emanating from the image display device is enabled to be totally reflected at the third surface.

When the angle of reflection at the third surface is too large, the prism optical element is long in a direction vertical to the axis of sighting (tangential direction). Particularly, in the case of a wide-angle image display apparatus, the off-axial ray spreads to such an extent that it cannot reach the first surface at which it is reflected next, so that the prism optical element cannot be realized. Therefore, it is desirable that the given light ray emanating from the image display device be set at not more than  $60^\circ$  which is the upper limit of the expression (1) at the third surface.

Further, it is desirable that the following expression (2) be satisfied:

$$\sin^{-1}(1/n_d) \leq \theta_a \leq 50^\circ \quad \dots (2)$$

Since the third surface is a curved surface inclined or decentered with respect to the optical axis (axial principal ray), the smaller the angle of reflection at this surface is, the smaller the generation of aberrations due to decentring, particularly coma aberration is. Therefore, it is desirable that the

given light ray emanating from the image display device be set at not more than  $50^\circ$  which is the upper limit of the expression (2) at the third surface.

Moreover, to realize an inexpensive image display apparatus, it is important that at least one of the surfaces constituting the prism optical element be a plane. Since the other surfaces can be defined with the at least one plane as the reference, mechanical design and manufacture of the optical system can easily be performed. This enables reduction in processing time, a simplified overall layout of the apparatus and the like, so that a large cost reduction can be realized.

Moreover, similar effects can be obtained by at least one surface being a spherical surface. In that case, since it is easy to define the other surfaces with one spherical surface as the reference, the overall layout of the apparatus and the like are simplified, so that a large cost reduction is enabled.

It is desirable that the refractive index  $n$  of the medium of the prism optical element be higher than 1.3.

It is apparent from the description given above that a viewing optical system can be structured by disposing the prism optical element in the viewing optical system.

In that case, the prism optical element may be disposed in the objective lens, or may be disposed in a position that is in the rear of the objective lens and in image erecting means for erecting an object image formed by the objective lens. In the latter, the prism optical element may be provided with both an image erecting property and an eyepiece lens property.

Moreover, the prism optical element of the present invention may be used as a head-mounted image display apparatus having image forming means comprising an LCD (liquid crystal display device) or a CRT disposed so as to be opposed to the fourth surface of the above-described prism optical element, or image forming means comprising an LCD, a CRT or the like relayed by a relay optical system, and a holding member that holds the prism optical element and the image forming means on the viewer's face, wherein a luminous flux emanating from the

image forming means is, in the order of optical paths in the prism optical element, incident on the fourth surface, reflected at the third surface, reflected at the first surface, reflected at the second surface, and exits from the first surface.

In the present invention, one surface may be used both as the second surface and the third surface. In that case, since the physical number of surfaces can be reduced by one, the process can be simplified in optical design and in prism manufacture, which contributes to mass productivity and price reduction. Further, it is desirable that physically one surface having both the property of the second surface and the property of the third surface be used both as the second and the third surfaces and the areas in which the luminous flux is internally reflected be set so as to overlap each other, because size reduction of the prism member can be realized.

Moreover, in an image viewing apparatus of the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system has a prism member having a surface structure provided with at least three surfaces among which a single medium having a refractive index ( $n$ ) higher than 1 ( $n > 1$ ) is filled, the prism member internally reflects at least three times a light ray emanating from the image forming means, at least two of the at least three internal reflections is total reflection, at least one of the at least two total reflections is performed by a surface disposed on the viewer side of the single medium of the prism member, the surface is a curved surface that corrects an aberration caused by the internal reflection by the prism member, and in order that the outside world can be viewed through at least two of the at least three surfaces of the prism member, the at least two surfaces are disposed opposed to each other so as to decrease distortion caused when the outside world is viewed with the single medium sandwiched therebetween.

In the image viewing apparatus of the present invention, since a third surface 5 is a totally reflecting surface and is not covered with reflective coating, the outside world light passing through the third surface 5 and a first surface 3 reaches the viewer's eye ball 15. Consequently, the outside



world can be viewed in an area  $\alpha$  different from the electronic image viewing area  $\beta$ . That the viewer can view the outside world image and the electronic image in different partial areas as mentioned above indicates, for example, that the viewer can simultaneously view the outside world in an upper area and the electronic image in a lower area in the viewer's field of view. The different partial areas may be areas arranged in any direction and parts such as upper and lower areas or left and right areas as long as the viewer can view the two images in different partial areas, respectively. By providing such a function, the viewer can recognize the outside world while wearing the image display apparatus, so that a safe image display apparatus can be provided that can prevent danger and deal with emergencies. As a result, the area of application as an image display apparatus is widened.

In the image forming apparatus, it is desirable that the image forming means be an image display device (one relayed by the relay optical system is not predetermined) such as an LCD or a CRT of which image formed screen is disposed so as to be opposed to the fourth surface and the second surface be a curved surface.

Moreover, the image forming apparatus can be structured as a head-mounted image display apparatus by providing a holding member that holds the image display device and the eyepiece optical system in front of the viewer's eye ball, and forming the prism member so that the luminous flux emanating from the image display device is incident on the fourth surface, the incident luminous flux is reflected at the third surface, the reflected luminous flux is reflected at the first surface, the reflected luminous flux is reflected at the second surface and the reflected luminous flux exits from the first surface.

Moreover, in the image viewing apparatus, it is desirable that the prism member can be fixed in the same position both when an image formed by the image forming means is viewed and when the outside world image is viewed, and in that case, as described below with reference to FIG. 7, the image from the image forming means and the outside world image can be viewed in different

partial areas through the first surface and the third surface.

The prism member may be provided with switching means for switching between viewing of an image formed by the image forming means and viewing of the outside world image, and be moved by the switching means.

That is, by moving the prism member so that the first surface of the eyepiece optical system disposed immediately before the viewer's eye ball and the third surface disposed on the outside world side and totally reflecting part of the principal ray are in the vicinity of the viewer's axis of sighting, the outside world image can be viewed in the periphery of the axis of sighting when the viewer faces straight forward, that is, in the vicinity of the center of the field of view, so that the viewer can recognize the outside world before his eyes while wearing the image display apparatus. Consequently, an image display apparatus ensuring safety can be realized.

Moreover, in a structure where the electronic image is kept displayed, by moving and returning the eyepiece optical system, the outside world image and the electronic image can be recognized while switching therebetween is made, so that the area of application is widened.

In this case, it is desirable for the switching means to move the prism member so that the optical path from the prism member to the viewer's eye ball when an image formed by the image forming means is viewed substantially coincides with the optical path from the prism member to the viewer's eye ball when the outside world image is viewed.

Moreover, in a structure where the prism member is moved in a direction along a plane including the optical path of the axial principal ray, since the prism member is linearly moved, the moving mechanism and the overall layout of the apparatus are simplified, so that an inexpensive image display apparatus can be realized.

Moreover, in a structure where the prism member is movable in a direction vertical to the axis of sighting, since not only the overall layout of the apparatus and the moving mechanism are simplified but also the amount of forward protrusion from the viewer is the same even after the

eyepiece optical system is moved, a small-size and compact image display apparatus can be provided.

Moreover, in a structure where the prism member is rotatable, since the outside world can be viewed by moving the prism member with a simple rotating mechanism, the mechanism itself is inexpensive, and further, in a structure where the prism members on the left and on the right are simultaneously rotated, the outside world can be recognized with both eyes, so that safety increases and the layout of the apparatus can be realized with a simple structure.

Moreover, in another image viewing apparatus of the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system includes at least a prism member, the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces and a surface other than the four surfaces is filled with a single medium having a refractive index ( $n$ ) higher than 1 ( $n > 1$ ), the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface, the prism member is structured so that at least the third surface has a total reflection property, and the first surface, the single medium and the third surface are structured so as to have an outside world viewing property that enables the outside world to be viewed through the first surface, the single medium and the third surface. In this case, the surface other than the four optical property surfaces is a prism side surface or a cut surface having no optical

property.

These image viewing apparatuses are structured so that the outside world can be viewed through a surface disposed immediately before the viewer's eye ball and a surface disposed on the outside world side of the eyepiece optical system. This action and effect will be described with reference to FIG. 7. FIG. 7 is a cross-sectional view of a decentered prism 12 in which a space formed by four surfaces 3, 4, 5 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1. In the figure, reference numeral 1 represents the viewer's eye, reference numeral 2 represents the viewer's axis of sighting, reference numeral 3 represents a first surface of an eyepiece optical system 12, reference numeral 4 represents a second surface, reference numeral 5 represents a third surface, reference numeral 6 represents a fourth surface, reference numeral 7 represents an image display device, reference numeral 12 represents the eyepiece optical system, reference numeral 15 represents the viewer's eye ball, and reference numeral 16 represents an optical filter. The actual light ray path from the image display device 7 is such that the light ray emanating from the image display device 7 is incident on the fourth surface 6 of the eyepiece optical system 12, totally reflected at the third surface 5, totally reflected at the first surface 3, reflected at the second surface 4, and again passes through the first surface to project an image onto the viewer's eye ball 15 with the viewer's pupil 1 as the exit pupil.

In the image viewing apparatus of the present invention, since the third surface 5 is a totally reflecting surface and is not covered with reflective coating, the outside world light passing through the third surface 5 and the first surface 3 reaches the viewer's eye ball 15. Consequently, the outside world can be viewed in an area  $\alpha$  different from the electronic image viewing area  $\beta$ . That the viewer can view the outside world image and the electronic image in different partial areas as mentioned above indicates, for example, that the viewer can simultaneously view the outside world in an upper area and the electronic image in a lower area in the viewer's field of view. The different partial areas may be areas arranged in any direction and parts such as upper and lower areas

or left and right areas as long as the viewer can view the two images in different partial areas, respectively. By providing such a function, the viewer can recognize the outside world while wearing the image display apparatus, so that a safe image display apparatus can be provided that can prevent danger and deal with emergencies. As a result, the area of application as an image display apparatus is widened.

In the image forming apparatus, it is desirable that the image forming means be an image display device (one relayed by the relay optical system is not predetermined) such as a CLD, a CRT or the like of which image formed screen is disposed so as to be opposed to the fourth surface and the second surface be a curved surface.

Moreover, the image forming apparatus can be structured as a head-mounted image display apparatus by providing a holding member that holds the image display device and the eyepiece optical system before the viewer's eye ball, and forming the prism member so that the luminous flux emanating from the image display device is incident on the fourth surface, the incident luminous flux is reflected at the third surface, the reflected luminous flux is reflected at the first surface, the reflected luminous flux is reflected at the second surface and the reflected luminous flux exits from the first surface.

Moreover, in the image forming apparatus, it is desirable that the surface disposed immediately before the viewer's eye ball and the surface disposed on the outside world side of the eyepiece optical system be formed so that the composite optical power in given positions of the two surfaces is substantially zero with respect to the outside world light. When the composite optical power of the two surfaces with respect to the outside world light is substantially zero, the outside world image viewed through the image forming apparatus is substantially equal to the outside world viewed with the naked eye, so that a more natural outside world image can be viewed. Consequently, danger can be prevented and the outside world can precisely be recognized in an emergency, so that a very safe image display apparatus can be provided.

In this case, the first surface and the third surface may be curved surfaces, spherical surfaces or plane surfaces. When the viewer views the outside world, the light ray from the outside world passes through the totally reflecting area of the internally reflecting surface disposed on the outside world side and the refracting surface disposed immediately before the viewer's eye ball to be projected onto the viewer's pupil. By the two surfaces being not aspherical but spherical, the curvatures of the surfaces do not change, so that viewing of a more natural off-axial outside world image is facilitated. Moreover, in a structure where the first surface disposed immediately before the viewer's eye ball and the third surface disposed on the outside world side of the eyepiece optical system are plane surfaces, since the surfaces have no optical power, a natural outside world image can be viewed. Further, in a structure where the two surfaces are vertical to the viewer's axis of sighting and disposed so as to be parallel to each other, since the outside world is viewed merely through a transparent plate, a very natural outside world image can be viewed.

In these structures, when the composite optical power, with respect to the outside world light, in given positions of the surface disposed immediately before the viewer's eye ball and the surface disposed on the outside world side of the eyepiece optical system is  $\phi_u$ , it is desirable that the following expression be satisfied:

$$-0.5 \leq \phi_u \leq 0.5 \text{ (Dmm)} \quad \dots (3)$$

Here,  $\phi_u$  corresponds to each of the optical power  $\phi_u(yz)$  within a plane including the axial principal ray and the optical power  $\phi_u(xz)$  within a plane vertical to the surface including the axial principal ray. Since the magnification when the outside world light passes through the decentered prism can be set to a value close to 1 by satisfying the condition of the expression (3), a more natural outside world image can be viewed.

Moreover, in the image viewing apparatus, it is desirable that the prism member can be fixed in the same position both when an image formed by the image forming means is viewed and when the outside world image is viewed, and in that case, as described above with reference to FIG.

7, the image from the image forming means and the outside world image can be viewed in different partial areas through the first surface and the third surface.

The prism member may be provided with switching means for switching between viewing of an image formed by the image forming means and viewing of the outside world image, and be moved by the switching means.

That is, by moving the prism member so that the first surface of the eyepiece optical system disposed immediately before the viewer's eye ball and the third surface disposed on the outside world side and totally reflecting part of the principal ray are in the vicinity of the viewer's axis of sighting, the outside world image can be viewed in the periphery of the axis of sighting when the viewer faces straight forward, that is, in the vicinity of the center of the field of view, so that the viewer can recognize the outside world before his eyes while wearing the image display apparatus. Consequently, an image display apparatus ensuring safety can be realized.

Moreover, in a structure where the electronic image is kept displayed, by moving and returning the eyepiece optical system, the outside world image and the electronic image can be recognized while switching therebetween is made, so that the area of application is widened.

In this case, it is desirable that the surface disposed immediately before the viewer's eye ball and the surface disposed on the outside world side of the eyepiece optical system be formed so that the composite optical power of the two surfaces is substantially zero with respect to the outside world light. When the composite optical power of the two surfaces with respect to the outside world light is substantially zero, the viewer can view a more natural outside world image, so that danger can be prevented and emergencies can appropriately be dealt with. As a result, a very safe image display apparatus can be provided.

When the composite optical power, with respect to the outside world light, in given positions of the surface disposed immediately before the viewer's eye ball and the surface disposed on the outside world side of the eyepiece optical system is  $\phi_0$ , it is desirable that the following

expression be satisfied:

$$-0.5 \leq \phi_0 \leq 0.5 \text{ (1/mm)} \quad \dots (4)$$

Here,  $\phi_0$  corresponds to each of the optical power  $\phi_0(x/z)$  within a plane including the axial principal ray and the optical power  $\phi_0(y/z)$  within a plane vertical to the surface including the axial principal ray. Since the magnification when the outside world light passes through the decentered prism can be set to a value close to 1 by satisfying the condition of the expression (4), a more natural outside world image can be viewed.

In this case, it is desirable for the switching means to move the prism member so that the optical path from the prism member to the viewer's eye ball when an image formed by the image forming means is viewed substantially coincides with the optical path from the prism member to the viewer's eye ball when the outside world image is viewed.

Moreover, in a structure where the prism member is moved in a direction along a plane including the optical path of the axial principal ray, since the prism member is linearly moved, the moving mechanism and the overall layout of the apparatus are simplified, so that an inexpensive image display apparatus can be realized.

Moreover, in a structure where the prism member is movable in a direction vertical to the axis of sighting, since not only the overall layout of the apparatus and the moving mechanism are simplified but also the amount of forward protrusion from the viewer is the same even after the eyepiece optical system is moved, a small-size and compact image display apparatus can be provided.

Moreover, in a structure where the prism member is rotatable, since the outside world can be viewed by moving the prism member with a simple rotating mechanism, the mechanism itself is inexpensive, and further, in a structure where the prism members on the left and on the right can simultaneously be rotated, the outside world can be recognized with both eyes, so that safety increases and the layout of the apparatus can be realized with a simple structure.

In still another image viewing apparatus of the present invention having image forming means and an eyepiece optical system that directs an image formed by the image forming means to a viewing eye ball, the eyepiece optical system includes at least a prism member, the prism member has, in its surface structure, at least four optical property surfaces having an optical property of transmission or reflection, a space surrounded by the four optical property surfaces and a surface other than the four surfaces is filled with a single medium having a refractive index ( $n$ ) higher than 1 ( $n > 1$ ), the four optical property surfaces comprise: a first surface having a transmission property and a reflection property, and disposed on a side of a viewer's eye ball; a second surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be at least decentered or inclined with respect to the viewer's axis of sighting; a third surface having a reflection property and disposed so as to be opposed to the first surface with the medium in between and to be substantially adjacent to the second surface; and a fourth surface disposed so that one end thereof is substantially adjacent to the first surface and the other end thereof is substantially in the vicinity of the third surface, the prism member is structured so that at least the second surface or the third surface has a total reflection property, and line of sight detecting means for detecting the viewer's line of sight is disposed in the vicinity of an area where total reflection by the second surface or the third surface having the total reflection property is caused. In this case, the surface other than the four optical property surfaces is also a prism side surface or a cut surface having no optical property.

Now, the action and effect when the image viewing apparatus is structured as an image display apparatus will be described. The disposition of the line of sight detecting means in the vicinity of the optical system enables detection of the viewer's line of sight. The detection of the line of sight will be described with reference to FIGs. 5 and 6. (a) of FIG. 5 is a cross-sectional view of an image display apparatus comprising a decentered prism 12 in which a space formed by three surfaces 3, 4 and 6 decentered with respect to the optical axis is filled with a medium having a

refractive index higher than 1, and an image display device 7. (b) of FIG. 5 is a cross-sectional view of an image display apparatus comprising a decentered prism 12 in which a space formed by four surfaces 3, 4, 5 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and an image display device 7. FIG. 6 is a cross-sectional view of another image display apparatus comprising a decentered prism 12 in which a space formed by four surfaces 3, 4, 5 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and an image display device 7. In the figures, reference numeral 1 represents the viewer's pupil, reference numeral 2 represents the viewer's axis of sighting, reference numeral 3 represents a first surface of an eyepiece optical system 12, reference numeral 4 represents a second surface, reference numeral 5 represents a third surface, reference numeral 6 represents a fourth surface, reference numeral 7 represents the image display device, reference numeral 9 represents a line of sight detecting optical system, reference numeral 10 represents a line of sight detector, reference numeral 11 represents illuminating means, reference numeral 12 represents the eyepiece optical system, and the reference numeral 15 represents the viewer's eye ball.

(a) of FIG. 5 is a view in which the line of sight detecting means 9 and 10 are disposed on the outside world side opposed to the viewer's eye ball 15 with the decentered prism of the eyepiece optical system 12 in between. In this case, it is necessary for the image of the viewer's pupil 1 to pass through the first surface 3 disposed immediately before the viewer's pupil 1 and the second surface 4 which is a reflecting surface disposed on the outside world side of the eyepiece optical system 12, to be incident on the line of sight detecting means 9 and 10. However, since the second surface 4 disposed on the outside world side of the eyepiece optical system 12 is a reflecting surface covered with reflective coating, to direct the image of the viewer's pupil 1 to the line of sight detecting means 9 and 10, it is necessary for the reflecting surface to have a part NC not covered with reflective coating (coating hole), which has a detrimental effect on the image being viewed.

(b) of FIG. 5 and FIG. 6 show image display apparatuses which are image viewing

apparatuses of the present invention. The third surface 5 which is a reflecting surface disposed on the outside world side of the eyepiece optical system 12 is set so that a part thereof totally reflects light. It is unnecessary to cover the totally reflecting part with reflective coating because the totally reflecting part reflects light from the image display device 7 without covered with reflective coating, and the image of the viewer's pupil 1 passes through the first surface 3 disposed immediately before the viewer's pupil 1 and the totally reflecting part of the third surface 5 disposed on the outside world side of the eyepiece optical system, so that the image of the viewer's pupil can be detected by the line of sight detecting means 9 and 10. Consequently, the line of sight can be detected without forming the coating hole that has a detrimental effect on viewing of the electronic image in the reflecting surface of the eyepiece optical system.

In this case, it is desirable for the first surface of the decentered prism to have a total reflection property. In this case, it is desirable for the line of sight detecting means to be disposed in a position to detect the viewer's line of sight through the second surface or the totally reflecting area of the third surface.

Moreover, it is desirable to provide the illuminating means for illuminating the viewer's eye ball. In this image display apparatus, the viewer's line of sight can precisely be detected because a bright image can be detected by illuminating the viewer's eye ball. Moreover, it is desirable that the illuminating means be disposed on the outside world side of the eyepiece optical system. When the illuminating means 11 is disposed between the viewer's face and the eyepiece optical system 12 like (a) of FIG. 5, there is a possibility that it interfaces with glasses or the like. However, by disposing the illuminating means 11 on the outside world side of the eyepiece optical system 12 like (b) of FIG. 5, the interference with the viewer's face can be avoided. Further, by disposing the illuminating means 11 so that the illuminating light from the illuminating means 11 passes through the totally reflecting part of the reflecting surface of the eyepiece optical system 12, the viewer's pupil can be illuminated without the coating hole formed. Moreover, it is desirable for

the illuminating means to use infrared light. That an electronic image is viewed indicates that the viewer's pupil is illuminated by light of the image display device. In the line of sight detecting means required to capture a feeble virtual image and perform image analysis such as one employing a corneal reflect method, it is necessary to eliminate the reflection image caused by the luminous flux of the image display device of which light emanation amount changes from moment to moment. Normally, the image display device is an LCD or the like, and the emanating light is in a waveband of the visible region. Therefore, the influence of light from the image display device can be reduced by the illuminating means using infrared light.

In this case, the image viewing apparatus can also be structured as a head-mounted image display apparatus by providing a holding member that holds the eyepiece optical system, the image forming means and the line of sight detecting means before the viewer's face.

Moreover, the image forming apparatus can be provided with positioning means for positioning the image forming means and the eyepiece optical system with respect to the viewer's head.

Further, it can be made possible to view a three-dimensional image or the like with both eyes by providing supporting means for supporting at least two pairs of such image forming apparatuses with a predetermined interval in between.

Next, in an image display apparatus according to the present invention having an image display device and an eyepiece optical system that directs an image formed by the image display device so that it can be viewed as a virtual image, the eyepiece optical system includes: a decentered prism in which a space formed by at least two surfaces is filled with a medium having a refractive index higher than 1 and at least one of a first surface situated immediately before the viewer's eye ball and a second surface which is a reflecting surface opposed to the first surface is a curved surface decentered or inclined with respect to the viewer's axis of sighting, and aberration correcting means disposed outside the second surface and for correcting aberrations caused with respect to the outside



world light on the first surface and the second surface by decentering.

In the image display apparatus, when the outside world image is viewed through the first surface situated immediately before the viewer's eye ball and the second surface which is a reflecting surface opposed to the first surface, since at least one of the two surfaces is decentered or inclined with respect to the viewer's axis of sighting, the viewed outside world image is similar to one viewed through a lens having an optical power biased asymmetrically with respect to the optical axis. Therefore, by disposing aberration correcting means such as a Fresnel lens that cancels the optical power of the second surface biased toward the outside world side, the viewer can view a more natural outside world image. Further, since the Fresnel lens is a very thin optical element, a small-size image display apparatus can be provided without the size increased.

Moreover, in the present invention, the Fresnel lens may be replaced by a different optical element such as a diffraction optical element or a holographic optical element as long as the above-mentioned effect is obtained.

When a Fresnel lens is used, it is desirable that the center of the zone of the Fresnel lens be situated within a plane including the optical path of the axial principal ray from the image display device and the Fresnel lens be decentered vertically to the axis of sighting within the plane including the optical path of the axial principal ray. The use of a Fresnel lens having an axially symmetrical configuration which is excellent in manufacturability enables cost reduction. By disposing a Fresnel lens having an axially symmetrical optical power so as to be decentered with respect to the axis of sighting within the plane including the optical path of the axial principal ray, aberrations caused with respect to the outside world light on the first surface and the second surface by decentering can more excellently be corrected.

Moreover, the Fresnel lens may be disposed in a manner such that the center of the zone of the Fresnel lens is situated on the plane including the optical path of the axial principal ray, that the Fresnel lens is inclined with respect to the axis of sighting and that the direction of the inclination is

along the configuration of the second surface. Disposing the Fresnel lens along the configuration of the second surface is disposing it so as to be inclined with respect to the viewer's axis of sighting. Therefore, the optical power can be set to a biased optical power being asymmetrical with respect to the optical axis, so that aberrations caused with respect to the outside world light on the first surface and the second surface by decentering can more excellently be corrected. Further, the amount of protrusion with respect to the viewer and the space between the eyepiece optical system and the Fresnel lens are reduced, so that a very compact image display apparatus without an unnecessary space can be provided.

In another image forming apparatus of the present invention having an image display device and an eyepiece optical system that directs an image formed by the image display device so that it can be viewed as a virtual image, the eyepiece optical system includes a decentered prism in which a space formed by at least three surfaces is filled with a medium having a refractive index higher than 1, the at least three surfaces comprise a reflecting and internally reflecting surface situated immediately before the viewer's eye ball, an outside world side internally reflecting surface disposed on the outside world side of the eyepiece optical system so as to be opposed to the reflecting and internally reflecting surface, and a refracting surface on which the luminous flux emanating from the image display device is incident, at least one of the surfaces is decentered or inclined with respect to the viewer's axis of sighting, and internal reflection occurs at least three times; and a second optical element that cancels the optical power caused with respect to the outside world light on the second surface when the outside world is viewed through the refracting and internally reflecting surface situated immediately before the viewer's eye ball and the outside world side reflecting surface, and the second optical element is disposed on the outside world side of the outside world side internally reflecting surface.

When the outside world image is viewed through the first surface situated immediately before the viewer's eye ball and the second surface which is a reflecting surface opposed to the first

surface, since at least one of the two surfaces is decentered or inclined with respect to the viewer's axis of sighting, the viewed outside world image is similar to one viewed through a lens having a biased optical power that varies according to the image height. Therefore, by disposing the second optical element that cancels the biased optical power caused with respect to the outside world light on the second surface, on the outside world side of the eyepiece optical system, the viewer can view a more natural and wider-area outside world image. Consequently, a safe image display apparatus can be provided that can prevent danger and deal with emergencies.

In this case, the eyepiece optical system may comprise a decentered prism in which a space formed by four surfaces is filled with a medium having a refractive index higher than 1, the four surfaces comprise a first surface which is a refracting and reflecting surface situated on the side of the viewer's eye ball, a second surface which is a reflecting surface opposed to the first surface, a third surface which is a reflecting surface opposed to the first surface and adjoining the second surface, and a fourth surface which is a refracting surface closest to the image display device, and at least one of the surfaces is decentered or inclined with respect to the viewer's axis of sighting. When the eyepiece optical system comprises four surfaces as described above, the outside world is recognized by the outside world light having passed through the first surface and the second surface. In that case, by disposing a second optical element that cancels the biased optical power only in an area covered by the second surface, an additional function can be realized without the overall size of the eyepiece optical system increased.

Moreover, it is desirable to dispose at least one second optical element on the outside world side of the second surface or the third surface so that the outside world can be viewed through the first surface, the second surface and the second optical element, or the first surface, the third surface and the second optical element. By disposing the second optical element that cancels the biased optical power on the outside world side of the second surface, a natural outside world image can be viewed in an area substantially the same as the area in which the electronic image is viewed.

Likewise, by disposing the second optical element that cancels the biased optical power on the outside world side of the third surface, a natural outside world image can also be viewed in an area different from the area in which the electronic image is viewed. By disposing two second optical elements one on the outside world side of the second surface and the other on the outside world side of the third surface, the viewer can view all the outside world images that pass through the first and the second surfaces and the first and the third surfaces. Consequently the outside world viewing angle is wider than the electronic image viewing angle, so that a natural and wide-area outside world image can be viewed. As a result, a very safe image display apparatus can be provided that can prevent danger and appropriately deal with emergencies.

Moreover, it is desirable for the second optical element to simultaneously cancel the composite optical power of the first and the second surfaces or the first and the third surfaces with respect to the outside world light. By forming the second optical element that simultaneously cancels the composite optical powers of the first and the second surfaces and the first and the third surfaces with respect to the outside world light, of one optical element, and disposing it on the outside world side of the eyepiece optical system, a wide area of outside world can be viewed. Since this second optical element simultaneously cancels the composite optical power, there is no gap in the outside world image, so that a more natural outside world image can be viewed. Consequently, a wide area of outside world can be recognized with one optical element, so that a low-cost and safer image display apparatus can be provided that can prevent danger and deal with emergencies.

Moreover, in the above-described structure, positioning means can be provided for positioning the image display device and the eyepiece optical system with respect to the viewer's head. By providing the positioning means for positioning the image display device and the eyepiece optical system with respect to the viewer's head, the viewer can view a stable electronic image.

Moreover, the image display apparatus can be mounted on the viewer's head by providing supporting means for supporting the image display device and the eyepiece optical system with respect to the viewer's head. By providing the supporting means for supporting the image display device and the eyepiece optical system with respect to the viewer's head so that the image display apparatus can be mounted on the viewer's head, the viewer can view the electronic image in whatever viewing positions and viewing directions he likes.

Further, supporting means for supporting at least two pairs of image display apparatuses with a predetermined interval in between can be provided. By providing the supporting means for supporting at least two pairs with a predetermined interval in between, the viewer can easily view images with the left and the right eyes. Moreover, by displaying images where a parallax is provided between the left and the right electronic images and viewing them with both eyes, a three-dimensional image can be enjoyed.

Moreover, the eyepiece optical system in the above-described image display apparatus can be used as an imaging optical system. The eyepiece optical system can be used as an imaging optical system such as a finder optical system of a camera as shown in FIG. 24 by forming it so as to image an object at infinity with the image display surface thereof as an image surface.

In the present invention, one surface may be used both as the second surface and the third surface. In that case, since the physical number of surfaces can be reduced by one, the process can be simplified in optical design and in prism manufacture, which contributes to mass productivity and price reduction. Further, by using physically one surface having both the property of the second surface and the property of the third surface as the second and the third surfaces and setting the areas in which the luminous flux is internally reflected so as to overlap each other, size reduction of the prism member can be realized.

[Embodiments of the Invention] Hereinafter, first to seventeenth embodiments of the image display apparatus according to the present invention will be described. In the structural

parameters of the embodiments described below, as typically shown in FIG. 1, an exit pupil 1 of an eyepiece optical system 12 is the origin of the optical system, an optical axis 2 is defined by a light ray passing through the center of display of an image display device 7 and the center (origin) of the exit pupil 1, the direction in which the optical axis 2 extends from the exit pupil 1 is the z-axis direction, the direction that is perpendicular to the z-axis, passes through the center of the exit pupil 1 and is within a plane where the light ray is bent by the eyepiece optical system 12 is the y-axis direction, a direction that is perpendicular to the z-axis and the y-axis and passes through the center of the exit pupil 1 is the x-axis direction, a direction from the exit pupil 1 to the eyepiece optical system 12 is the positive z-axis direction, a direction from the optical axis 2 to the image display device 7 is the positive y-axis direction, and a direction constituting a right-hand system together with the z-axis and the y-axis is the positive x-axis direction. Ray tracing is performed according to backward ray tracing with the exit pupil 1 side of the eyepiece optical system 12 as the object side and the image display device 7 side thereof as the image side.

With respect to the surfaces for which decentering amounts Y and X and an inclination amount  $\theta$  are provided, the decentering amounts Y and X and the inclination amount  $\theta$  represent the amounts of shift in the y direction and the z direction from the exit pupil 1 which is the origin of the optical system and the angle of inclination of the central axis of the surface with respect to the z-axis unless otherwise specified in the structural parameters (there is specification in the sixth and ninth embodiments). The angle of inclination is positive counterclockwise. When a reference surface is specified, the decentering amounts Y and X and the inclination amount  $\theta$  represent similar shift amounts and inclination angle from the vertex of the reference surface.

In the structural parameters shown below, axial distances in coaxial parts are shown as distances. In addition, the radii of curvature of the spherical surfaces, the refractive indices of the media and the Abbe numbers are shown according to the conventional method.

FIGs. 1 to 4, (b) of FIG. 5 and FIGs. 6 to 17 are cross-sectional views of image display

apparatuses of the first to the fourth, the fifth and the sixteenth to the seventeenth embodiments of the present invention including the optical axis. The embodiments of FIGs. 1 to 4, (b) of FIG. 5, FIGs. 6 to 11 and FIGs. 15 and 16 comprise a decentered prism 12 in which a space formed by four surfaces 3, 4, 5 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and the embodiment of FIG. 17 comprises a decentered prism 12 in which a space formed by three surfaces 3, 4 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1. In the figures, reference numeral 1 represents the viewer's pupil, reference numeral 2 represents the viewer's axis of sighting, reference numeral 3 represents a first surface of an eyepiece optical system 12, reference numeral 4 represents a second surface, reference numeral 5 represents a third surface, reference numeral 6 represents a fourth surface, reference numeral 7 represents an image display device, reference numeral 8 represents a Fresnel lens, reference numeral 9 represents a line of sight detecting optical system, reference numeral 10 represents a line of sight detector, reference numeral 11 represents illuminating means, reference numeral 12 represents the eyepiece optical system (decentered prism), reference numerals 13 and 14 represent second optical elements, reference numeral 15 represents the viewer's eye ball, reference numeral 16 represents an optical filter, reference numeral 17 represents a linear motor, reference numeral 18 represents protrusions provided on an optical element, and reference numeral 19 represents a guide (rail) provided on an exterior portion. With respect to the actual light ray path when an electronic image is viewed, in the embodiments of FIGs. 1 to 4, (b) of FIG. 5, FIGs. 6 to 11 and FIGs. 15 and 16, the light ray emanating from the electronic image on the image display device 7 is incident on the fourth surface 6 which is a refracting surface opposed to the image display device 7 of the eyepiece optical system 12, is reflected at one of the two surfaces 4 and 5 situated opposite to the viewer's face, the third surface 3 adjoining the fourth surface 6 toward the side of the viewer's pupil 1, is reflected at the first surface 3 disposed immediately before the viewer's pupil 1 in a direction for the light ray to recede from the viewer's pupil 1, is reflected at one

of the two surfaces 4 and 5 situated opposite to the viewer's face, the second surface 4 disposed immediately before the viewer's pupil 1 toward the side of the viewer's pupil 1, and passes through the first surface 3 to be projected within the viewer's eye ball 15 with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1. In the embodiment of FIG. 17, the light ray emanating from the electronic image on the image display device 7 is incident on the fourth surface 6 which is a refracting surface opposed to the image display device 7 of the eyepiece optical system 12, is reflected toward the side of the viewer's pupil 1 at an area (the third surface 5) adjoining the fourth surface 6, of the second surface 4 situated opposite to the viewer's face and used also as the third surface 5, is reflected at the first surface 3 disposed immediately before the viewer's pupil 1 in a direction for the light ray to recede from the viewer's pupil 1, is reflected toward the side of the viewer's pupil 1 at an area of the second surface 4 which area is situated opposite to the viewer's face and far from the fourth surface 6, and passes through the first surface 3 to be projected within the viewer's eye ball 15 with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1.

The cases shown in (b) of FIG. 5 and FIG. 6 are embodiments of the image display apparatus of the present invention having the line of sight detecting means. The third surface 5 which is a reflecting surface disposed on the outside world side of the eyepiece optical system 12 is set so that a part thereof totally reflects light. It is unnecessary to cover the totally reflecting part with reflective coating because the totally reflecting part reflects light from the image display device 7 without covered with reflective coating. The actual light ray path when the line of sight is detected is such that the illuminating light from the light source 11 passes through the third surface 5 and the first surface 3 of the eyepiece optical system 12 to illuminate the viewer's eye ball 15 and the light ray reflected thereat is incident on the first surface 3 disposed immediately before the viewer's pupil 1, passes through the totally reflecting area which is at least a part of the third surface 5 situated opposite to the viewer's face, and is directed to the line of sight detector 10 by the line of

sight detecting optical system 9 to form an image of the viewer's pupil 1. Needless to say, the illuminating means 11 using infrared light and the detector 10 detecting infrared light may be used to reduce the influence of light on the electronic image and the like. Further, the illuminating means 11 may be disposed in a position other than the shown position or in any position as long as the viewer's eye ball 15 can be illuminated.

FIG. 18 is a cross-sectional view of an embodiment in which similar line of sight detecting means comprising the line of sight detecting optical system 9, the line of sight detector 10 and the light source 11 is provided in the case of the eyepiece optical system 12 comprising the three surfaces 3, 4 and 6 decentered with respect to the optical axis like the seventeenth embodiment. The actual light ray path when the line of sight is detected will not be described because it is similar to that of (b) of FIG. 5 and FIG. 6.

The one shown in FIG. 7 is an embodiment of the image display apparatus of the present invention with which the electronic image and the outside world image can simultaneously be viewed through the eyepiece optical system 12. The actual light ray path when the outside world image is viewed is such that the light ray from the object point of the outside world is incident on the third surface 5, passes through the first surface 3 and is projected within the viewer's eye ball with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1. Further, by disposing on the outside world side of the third surface 5 an attenuating filter or the optical element 16 that adjusts the quantity of the outside world light, the viewer can easily view both or one of the electronic image and the outside world image. Moreover, by making the attenuating filter or the optical element 16 movable between the viewing areas  $\alpha$  and  $\beta$ , the light quantity of either the electronic image or the outside world image can be controlled.

The ones shown in FIGs. 8 and 9 are embodiments of another image display apparatus of the present invention with which the outside world image can be viewed by moving the eyepiece optical system 12. In FIG. 8, the eyepiece optical system 12 is shifted to the outside world image

viewing position of (b) of FIG. 8 by moving it from the electronic image viewing position of (a) of FIG. 8 in the negative Y direction with respect to the viewer's pupil. In FIG. 9, the eyepiece optical system 12 is shifted to the outside image viewing position of (b) of FIG. 9 by rotating it clockwise from the electronic image viewing position of (a) of FIG. 9 with respect to the viewer's pupil 1.

Consequently, in either case, the outside world can be viewed through the eyepiece optical system 12 in the direction of the viewer's axis of sighting. The light ray from the object point of the outside world is incident on the third surface 5 and passes through the first surface 3 to be projected within the viewer's eye ball with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1. Further, in (b) of FIG. 8, the viewer can view the electronic image in an area below the viewer's axis of sighting 2. The electronic image viewing direction may be any direction because it varies according to the manner of disposition or the direction of movement of the eyepiece optical system 12.

(c) of FIG. 8 and (c) of FIG. 9 each show an example of a mechanism for moving the eyepiece optical system 12. In either case, the eyepiece optical system 12 is moved along the guide (rail) 19 provided on the exterior portion by the linear motor 17 through the protrusions 18 provided on the optical element. In the case of (c) of FIG. 8, the guide (rail) 19 is linear, whereas in the case of (c) of FIG. 9, the guide (rail) 19 is arc-shaped, so that the eyepiece optical system 12 is linearly moved and rotated in these cases, respectively.

FIG. 19 shows an example in which in the case of the eyepiece optical system 12 comprising the three surfaces 3, 4 and 6 decentered with respect to the optical axis like the seventeenth embodiment, the eyepiece optical system 12 is shifted to the outside world image viewing position by moving it from the electronic image viewing position in the negative Y direction with respect to the viewer's pupil like the embodiment of FIG. 8. The action thereof will not be described because it is similar to that of FIG. 8.

The ones shown in FIGs. 10 to 14 are embodiments of the image display apparatus of the

present invention in which the Fresnel lens 8 which is the aberration correcting means is disposed on the optical path when the outside world image is viewed. The actual light ray path when the outside world image is viewed is such that the light ray from the object point of the outside world passes through the Fresnel lens 8 to be incident on the second surface 4 of the decentered prism and passes through the first surface 3 to be projected within the viewer's eye ball with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1. It is necessary to situate the Fresnel lens 8 in a predetermined position only when the outside world is viewed. When the outside world is not viewed, the Fresnel lens 8 may be situated in a different position by a moving mechanism that vertically moves or rotates the Fresnel lens 8, or the Fresnel lens 8 may be structured so as to be detachable when the outside world is not viewed.

Of FIGs. 10 to 14, in the cases of FIGs. 10 and 11, like FIG. 1 and the like, the eyepiece optical system (decentered prism) 12 comprises the four surfaces 3, 4, 5 and 6 decentered with respect to the optical axis and the light ray path when the electronic image is viewed is similar. However, the decentered prism 12 of FIG. 12 comprises the decentered prism 12 in which a space formed by the three surfaces 3, 4 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and the actual optical path when the electronic image is viewed is such that the light ray emanating from the electronic image on the image display device 7 is incident on the fourth surface (being third in the order of surfaces) 6 which is a refracting surface opposed to the image display device 7 of the eyepiece optical system 12, is reflected at the first surface 3 disposed immediately before the viewer's pupil 1 in a direction for the light ray to recede from the viewer's pupil 1, is reflected at the second surface 4 situated opposite to the viewer's face toward the side of the viewer's pupil 1, and passes through the first surface 3 to be projected within the viewer's eye ball 15 with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1.

Moreover, the decentered prism 12 of FIG. 13 comprises the decentered prism 12 in which

a space formed by the three surfaces 3, 4 and 6 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and the actual light ray path when the electronic image is viewed is such that the light ray emanating from the electronic image on the image display device 7 is incident on the fourth surface (being third in the order of surfaces) 6 which is a refracting surface opposed to the image display device 7 of the eyepiece optical system 12, is reflected at the second surface 4 situated opposite to the viewer's face toward the side of the viewer's pupil 1, and passes through the first surface 3 to be projected within the viewer's eye ball 15 with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1.

Moreover, the decentered prism 12 of FIG. 14 comprises the decentered prism 12 in which a space formed by the two surfaces 3 and 4 decentered with respect to the optical axis is filled with a medium having a refractive index higher than 1, and the actual light ray path when the electronic image is viewed is such that the light ray emanating from the electronic image on the image display device 7 is incident on the first surface 3 which is a refracting surface opposed to the image display device 7 of the eyepiece optical system 12, is reflected at the second surface 4 situated opposite to the viewer's face toward the side of the viewer's pupil 1, and passes through the first surface 3 to be projected within the viewer's eye ball 15 with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil 1.

Next, the ones shown in FIGs. 15 and 16 are embodiments of the image display apparatus of the present invention in which the second optical elements 13 and 14 that cancel the optical power caused on the two surfaces 3 and 4 or 3 and 5 with respect to the outside world light when the outside world is viewed through the first surface 3 of the eyepiece optical system 12 situated immediately before the viewer's eye ball and the second surface 4 or the third surface 5 which is an outside world side internally reflecting surface are disposed on the optical path when the outside world is viewed. The actual light ray path when the outside world image is viewed is such that the light ray from the object point of the outside world passes through the second optical element 13 or

- the other second optical element 14 to be incident on the second surface 4 or the third surface 5 of the decentered prism 12, and passes through the first surface 3 to be projected within the viewer's eye ball with the position of the viewer's iris or the center of rotation of the eye ball as the exit pupil
- 1.

A monocular image display apparatus may be structured by providing one pair of eyepiece optical system and image display device as described above, or a binocular image display apparatus may be structured by providing such a pair on each of the left and the right and holding them in positions spaced the interpupillary distance apart. By doing so, the present invention can be structured as a fixed or a portable image display apparatus with which images can be viewed with one eye or both eyes.

A case of the monocular image display apparatus is shown in FIG. 21 (in this case, mounted on the left eye), and a case of the binocular image display apparatus is shown in FIG. 22. In FIGs. 21 and 22, reference numeral 31 represents the main unit of the image display apparatus which is fixed by a supporting member through the head so as to be held before the left eye on the viewer's face in the case of FIG. 21 and before both eyes on the viewer's face in the case of FIG. 22. The supporting member comprises left and right front frames 32 having one ends joined to the main unit 31 and extending from the viewer's temples to above the viewer's ears, and left and right rear frames 33 joined to the other ends of the front frames 32 and extending along side parts of the viewer's head (in the case of FIG. 21), or comprises, in addition to the front and the rear frames 32 and 33, a vertex frame 34 having its ends joined to the other ends of the left and right rear frames 33, respectively, so as to be sandwiched therebetween, and supporting the vertex part of the viewer's head (in the case of FIG. 22).

Moreover, in the vicinity of the joins of the front frames 32 to the rear frames 33, rear plates 35 comprising an elastic body such as a metal plate spring are joined. The rear plates 35 are each joined so that a rear cover 36 constituting a part of the supporting member is situated in the rear of the viewer's ear in a part ranging from the back of the head to the base of the neck so as to be supportable (in the case of FIG. 22). A speaker 39 is attached in a position corresponding to each of the viewer's ears within the rear plate 35 or the rear cover 36.

A cable 41 for externally transmitting signals such as video and sound signals passes from

the main unit 31 through the vertex frame 34 (in the case of FIG. 22), the rear frame 33, the front frame 32 and the rear plate 35 to outwardly protrude from the rear end of the rear plate 35 or the rear cover 36. The cable 41 is connected to a video reproducing apparatus 40. In the figure, reference numeral 40a represents a switch and a volume controller of the video reproducing apparatus 40.

An end of the cable 14 may be a jack so that the cable 41 is attachable to an existing video deck or the like. Further, the cable 41 may be connected to a TV tuner to realize an image display apparatus for TV watching, or may be connected to a computer so that computer graphics images or messages images from the computer are received. Moreover, to exclude the obstructive code, an antenna may be connected so that external signals are received by radio waves.

When used as an imaging optical system, the eyepiece optical system of the image display apparatus of the present invention can be used, for example, as a finder optical system Fi of a compact camera Ca as shown in FIG. 23 in which a taking optical system Ob and the finder optical system Fi are separately provided. The structure of an optical system when the eyepiece optical system is used as an imaging optical system is shown in FIG. 24. An objective optical system L<sub>1</sub> can be formed of a front lens unit GF, an aperture diaphragm D and the eyepiece optical system DS of the present invention disposed in the rear thereof. The image formed by the objective optical system L<sub>1</sub> is erected by a four-reflection Porro prism P provided on the viewer side of the objective optical system L<sub>1</sub>, and viewed through an eyepiece lens Oc.